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ON THE THEORY OF DISPERSION OF X-RAYS

By R. de L. Kronig

ABSTRACT

After a brief summary of the ideas underlying the quantum theory of dispersion it is shown that it can be applied to the refraction of x-rays, although the assumption that the number of atoms in a wave length cube is large is no longer satisfied. A general formula for the index of refraction in terms of the atomic absorption coefficient α and the critical frequencies is given. From the condition, experimentally verified, that the electrons in the atom for impressed frequencies, large compared to their natural frequencies, shall act like free electrons as far as the index of refraction is concerned, a relation is obtained for α. From the failure of this relation when applied to the groups of electrons separately, conclusions are drawn as to the coupling of the groups. Some considerations on the origin of the Compton shifted radiation are added, from which it appears that in the wave description this radiation must be regarded as coming from all the atoms and as being coherent with the incident waves; a result suited to stress the difficulty of harmonizing the wave picture with that of quantum processes in the atoms.[1]

1. THE GENERAL DISPERSION THEORY

As is well known, a great many features of the phenomena arising from the action of external radiation upon matter in bulk can be qualitatively described by the classical theories. It is there assumed that all the atoms contain electric charges elastically and, in general, isotropically bound to equilibrium positions, having a damping proportional to their velocity. Under the influence of the radiation the resonators perform forced oscillations with the impressed frequency. On account of these oscillations they will emit spherical wavelets, their induced electric moment being parallel to, and almost in phase with, the electric field of the incident waves as long as the impressed frequency is sufficiently remote from any of the natural frequencies of the reson-

[1] As Professor Kramers kindly informs me, he too has obtained most of the results derived here. (To be published shortly.)

ators. These wavelets represent the scattered radiation, and by their interference with the primary waves they give rise to the retardation or acceleration of phase which causes the phenomenon of dispersion. When one of the natural frequencies of the resonators is approached by the impressed frequency, the amplitude of the forced oscillations becomes very large, and, moreover, they will be considerably out of phase with the electric field of the incident waves. The scattering increases markedly (resonance), and due to the phase shift, the wavelets produce a diminution of the amplitude of the incident wave (absorption). Finally, when the impressed frequency gets much greater than the natural frequency of a resonator, its charge will act as if free.

The induced electric moment of an atom containing charges $e_1, e_2, \ldots . e_f$ of mass $m_1, m_2, \ldots . m_f$ and capable of performing free oscillations about an equilibrium position with frequencies $\omega_1, \omega_2, \ldots . \omega_f$ respectively is known to be

$$\mathfrak{M}(t) = \mathfrak{E} \sum_{i=1}^{f} \frac{e_i^2 \cos 2\pi\nu t}{4\pi^2 m_i(\omega_i^2 - \nu^2)} \tag{1}$$

if the impressed field at the point of the atom is given by

$$\mathfrak{E}(t) = \mathfrak{E} \cos 2\pi\nu t \ , \tag{2}$$

and ν is sufficiently different from the ω_i. The total amount of energy absorbed on the average by a resonator in a time dt from a radiation field, whose density $\rho(\nu)$ does not vary appreciably in the neighborhood of the natural frequency ω_i, is given by

$$\alpha_i c \rho(\omega_i) dt = \frac{\pi e_i^2}{m_i} \rho(\omega_i) dt \, ,$$

where c is the velocity of light and α_i may be called the total atomic absorption coefficient for the resonator i.[2] Hence (1) may be written

$$\mathfrak{M}(t) = \mathfrak{E} \sum_{i} \frac{c\alpha_i \cos 2\pi\nu t}{4\pi^3(\omega_i^2 - \nu^2)} . \tag{3}$$

The wave theory seems to be the only picture which affords an adequate description of the phenomenon of dispersion and its connection with absorption.[3] Its ideas are therefore utilized in the quantum

[2] α_i is then the integral of the absorption coefficient over all frequencies, considering the absorption curve as approaching zero on both sides of the natural frequency. In reality the absorption coefficient at large frequencies approaches a small positive value corresponding to the scattering of a free charge. This part of the absorption coefficient has to be subtracted.

[3] N. Bohr, Zs. f. Phys. *13*, p. 161; 1923.

theory of dispersion by ascribing also here a scattering moment to every atom. Since, however, according to our knowledge of atomic structure, the picture of elastically and isotropically bound charges in the atom is not to be harmonized with other facts, Kramers[4] investigated the perturbations arising in a multiply periodic system under the influence of an external field of the form (2) and found an expression for the induced scattering moment of an atom by introducing for the quantities characteristic of the multiply periodic system their quantum analogues. In the case of a large number of atoms in their normal state, oriented at random and having absorption lines at the frequencies ω_i, his general expression for the average scattering moment per atom reduces to[5]

$$\mathfrak{M}(t) = \mathfrak{E} \sum_i \frac{f_i e^2 \cos 2\pi\nu t}{4\pi^2 m(\omega_i^2 - \nu^2)} . \tag{4}$$

Here e and m are respectively the charge and mass of an electron, so that the atom acts as if containing resonators of charge $f_i e$ and mass $f_i m$. Kramers' expression for f_i may be written

$$f_i = \frac{mh\omega_i b_i}{\pi e^2} ,$$

where h is Planck's constant and b_i is defined by

$$P_i dt = b_i \rho(\omega_i) dt .$$

$P_i dt$ denotes the probability of an atom being lifted from the normal state to the state i in the time dt under the influence of a radiation field whose energy density between frequencies ω_i and $\omega_i + d\omega$ is $\rho(\omega_i)d\omega$. $b_i h\omega_i \rho(\omega_i)dt$ represents the energy absorbed on the average per atom in the time dt and may hence be put equal to $\alpha_i c\rho(\omega_i)dt$. This gives

$$f_i = \frac{mc\alpha_i}{\pi e^2} . \tag{5}$$

Introducing in (4) leads to the old expression (3) for the scattering moment of an atom. In fact, equation (4) was first derived by Laden-

[4] H. A. Kramers, Nature, *113*, p. 673; *114*, p. 310, 1924; H. A. Kramers and W. Heisenberg, Zs. f. Phys., *31*, p. 681; 1925. See also M. Born, Zs. f. Phys., *26*, p. 379; 1924 and J. H. van Vleck, Phys. Rev., *24*, p. 344; 1924.

[5] This is identical with a formula obtained previously by R. Ladenburg, Zs. f. Phys., *4*, p. 451; 1921 in a different way; see also R. Ladenburg and F. Reiche, Naturwiss., *11*, p. 584; 1923.

burg from the viewpoint of the very intimate connection between dispersion and absorption inherent in the wave picture.

2. CALCULATION OF THE INDEX OF REFRACTION

On account of what follows, it will be necessary to recall how the expression for the index of refraction can be derived from (4). Consider an infinite slab of the substance perpendicular to the direction of propagation Z of the incident waves and of thickness dz, small compared to the wave length λ, so that all the resonators inside will be practically in phase, say $dz=q\lambda$, where q is a small fraction. Take a point P a distance l away from the slab and put the Z-axis through it. The slab may be divided into circular zones by cylinders about Z of radius ρ. Let the breadth of such a zone be $d\rho$. We now investigate the resultant electromagnetic field at P produced by the superposition of the spherical wavelets originating from the atoms in the slab under the influence of a plane wave. For this purpose we must make the breadth of the zones such that waves coming from atoms on the inner and outer boundaries of the zone are still practically in phase; i.e., $dr=q\lambda$, where r is the distance from P to the zone. But $\rho d\rho=rdr=rq\lambda\geqq lq\lambda$. Now the total volume of a zone is $2\pi\rho d\rho dz\geqq 2\pi lq^2\lambda^2$. But in order that one may be able, in computing the field at P, to integrate, it is necessary that in the volume $2\pi lq^2\lambda^2$ there is a considerable number n of atoms. This gives the condition for l

$$2\pi lq^2\lambda^2 N=n\ ,$$

$$l=\frac{n}{2\pi q^2\lambda^2 N}\ , \tag{6}$$

where N is the number of atoms per unit volume.

Using for the scattering moment of an atom the expression (4), one easily finds by integrating over all the radiation fields of the oscillating moments that at distances greater than l the wavelets emitted by the slab under the influence of the incident wave have been ironed out by interference approximately into a plane wave. If we regard the refracting medium as made up of such slabs, we can neglect the effect on the motion of the resonators in a slab of the waves coming backwards from the following slabs, provided the polarization produced in the medium by the field E of the incident wave is small compared to E (i.e., $/\mu-1/<<1$). Then the retardation in phase of the incident wave in going

through a slab, produced by the wave from the slab, corresponds to an index of refraction μ given by

$$\mu - 1 = \delta = \sum_i \frac{N e^2 f_i}{2\pi m(\omega_i^2 - \nu^2)}, \tag{7}$$

if all the atoms are of the same kind.

In the theory of dispersion in the optical region it is always assumed that there is a large number of atoms in a volume whose linear dimensions are of the same order of magnitude as the wave length, a condition generally satisfied in this region. The reason for the assumption is that, if the polarization of the substance is comparable to the electric field, then the only simple way of taking the effect of this polarization on an atom into account consists in imagining a sphere around the atom cut out of the substance. If the sphere can be so chosen that it contains many atoms, and yet its radius is small compared to the wave length, then the formulas for the polarization of a sphere in a uniform electric field can be applied. If, however, the polarization is very small so that it may be neglected, i.e., if μ does not differ much from unity, the preceding analysis shows that the above assumption no longer is necessary.[6] Equation (7) then holds even if there are few atoms in a wave length cube, but it must be remembered that if actual refraction is to take place, the optical path of the beam under investigation must be greater than l.

3. APPLICATION TO THE DISPERSION OF X-RAYS

In case a substance composed of atoms in their normal state is illuminated by x-rays, we meet a problem with a number of interesting features. In the first place, there are very few atoms in a wave length cube, both the wave length and the distances between atoms being of the order of 1ÅU. Nevertheless, the formula given for the index of refraction will apply since $\mu - 1 = \delta$ is found to be of the order 10^{-6}, and l according to (6) ranges for solids around 10^{-3} cm if we assume as reasonable values for q and $nq = 1/25$, $n = 25$; while the actual path of the beam in a spectrometer is several cm. Further we have a continuous manifold of excited stationary states instead of a discrete sequence.

Consider an electron in one of the inner orbits of the atom, say an n_k orbit. Upon its removal the electron may have any velocity v.

[6] For an elaborate mathematical discussion of the case of few atoms in a wavelength cube leading to the same conclusion the reader is referred to F. Reiche, Ann. d. Phys. *50*, pp. 1 and 121, 1916.

The ionized atom will in general be capable of two states[7] whose energy difference obeys the relativistic doublet formula, and which may be distinguished by a third quantum number j; when $k=1$, the ionized atom is capable of one state only. Thus if an electron be removed from a 1_1 orbit, the atom remains in the state designated as K, while if an electron be removed from a 2_2 orbit, the atom may remain either in the state L_{II} or L_{III}, forming the relativistic L-doublet, these two states having the values $j=1$ and $j=2$ respectively.[8] We may, therefore, characterize an excited state by (v,nkj), or using as abbreviation for the combination nkj the letter r, we can denote it by (v,r). Finally, we may call it (ω,r), where ω is the frequency corresponding to a transition from the normal state to the state (v,r). The continuous manifold of states (v,r) or (ω,r), where r is given and v variable, corresponds to an absorption band extending from the critical frequency ω_r toward larger frequencies.

With a frequency interval $d\omega$ of the continuous absorption band r there is to be associated a resonator of charge $f_r(\omega)d\omega \cdot e$ and mass $f_r(\omega)d\omega \cdot m$, where $f_r(\omega)d\omega$ according to (5) is given by

$$f_r(\omega)d\omega = \frac{cm\alpha_r(\omega)d\omega}{\pi e^2} . \tag{8}$$

Here $\alpha_r(\omega)$ is the atomic absorption coefficient at the frequency ω due to transfer of atoms to the state r. In the expression (7) for the index of refraction we have now instead of a summation an integration by ω, extending over the absorption band r from ω_r to ∞, and a summation over the various bands r and in addition terms corresponding to the lines associated with the transfer of outer electrons to higher stationary states. These latter each belong to a definite series limit at which an absorption band r begins and we may include them symbolically in the integration by extending it from 0 to ∞. For a substance composed of atoms of one kind, one finds from (7) and (8)

$$\mu - 1 = \delta = \sum_r \int_0^\infty \frac{Nc\alpha_r(\omega)d\omega}{2\pi^2(\omega^2 - \nu^2)} . \tag{9}$$

This expression will hold even on the short wave length side of the absorption edges except in their immediate neighborhood, although then some of the resonators have frequencies nearly coinciding with ν.

[7] Disregarding the different possible orientations of the orbits of the valence electrons.

[8] These are the values customarily used in x-ray notation; their ratio is that of the statistical weights of the two states.

The reason is that the resonators in the narrow region from ν to $\nu+\Delta\omega$, in which the damping would become of importance, have their contribution almost canceled by the resonators from $\nu-\Delta\omega$ to ν. This is no longer true at the edge, where the damping must be taken into account. For compounds or mixtures the value of δ will be found additively from the values due to the components.

To proceed further it is necessary to know something about $\alpha_r(\omega)$. The general result of the investigations on the true absorption coefficients of elements of atomic number Z not too low and for wave lengths in the region from 0.1 ÅU to 1 ÅU appears to be[9] that this coefficient is approximately expressible in the form

$$\alpha_r(\omega)=C_rZ^4\lambda^3=\frac{c^3C_rZ^4}{\omega^3}\,, \tag{10}$$

C_r being a constant more or less independent of the substance. Such expressions have been found to hold both on the short and long wave length side of the K-absorption limit, i.e., for the absorption due to the K- and L-electrons. The experimental data[10] on the refraction of x-rays have been obtained with frequencies ν large compared to the frequencies of most of the electrons in the atom. Since according to (10) $\alpha_r(\omega)$ decreases rapidly with ω, it is easily seen from (9) that the

[9] For a detailed discussion of the experimental evidence and references to the literature see H. A. Kramers, Phil. Mag., *46*, p. 836; 1923; see also F. K. Richtmyer, Phys. Rev., *27*, p. 1; 1926.

[10] Bergen Davis and H. M. Terrill, Proc. Nat. Ac., *8*, p. 537; 1922;
A. H. Compton, Phil. Mag., *45*, p. 1121; 1922;
C. C. Hatley and Bergen Davis, Phys. Rev., *23*, p. 290; 1924;
Bergen Davis and R. von Nardroff, Phys. Rev., *23*, p. 291; 1924; Proc. Nat. Ac., *10*, p. 60, 384; 1924;
C. C. Hatley, Phys. Rev., *24*, p. 486; 1924;
R. von Nardroff, Phys. Rev., *24*, p. 143; 1924;
E. Hjalmar and M. Siegbahn, Nature, *115*, p. 85; 1925;
A. Larsson, M. Siegbahn and T. Waller, Phys. Rev., *25*, p. 235; 1925.
Bergen Davis and C. M. Slack, Phys. Rev., *25*, p. 881; 1925;
M. Siegbahn, Journ. de Phys., *6*, p. 228; 1925;
Bergen Davis and C. M. Slack, Phys. Rev., *27*, p. 18; 1926.
A. Larson, Zs. f. Phys. *35*, p. 401; 1926;
I am indebted to Professor Davis and Mr. Slack for some additional unpublished material. This deals with the refraction of X-rays in silver on the long wavelength side of the K-limit. Below are given the values of $\delta.10^6$ as observed and as computed from the Lorentz formula and from (9) respectively: .707 Å.U.; $-5.3\pm.6$, -5.7, -6.0; .515 Å.U.; $-3.0\pm.4$, -2.1, -3.1; .500 Å.U., $-2.5\pm.3$, -1.0, -2.9; .485 Å.U., $-2.2\pm.3$, 16.4, -2.5.

contribution to δ of an absorption band due to such loosely bound electrons reduces very nearly to

$$-\frac{Nc}{2\pi^2\nu^2}\int_0^\infty \alpha_r(\omega)d\omega\ . \tag{11}$$

If ν is large compared to all the critical frequencies of the atom, then

$$\delta=-\frac{Nc}{2\pi^2\nu^2}\sum_r\int_0^\infty \alpha_r(\omega)d\omega\ .$$

Now the experimental values for δ in this case are found to check well with the value obtained by the classical theory on the assumption that all electrons act as if free:

$$\delta=-\frac{NZe^2}{2\pi m\nu^2}\ ,$$

where Z is the number of electrons per atom. From comparison there follows

$$\sum_r\int_0^\infty \alpha_r(\omega)d\omega=\frac{\pi Ze^2}{cm}\ .$$

This is a special case of a general condition formulated by Kuhn[11] and Thomas.[12] Kuhn, moreover, suggests from a consideration of the scattering activity of atoms at very high impressed frequencies that the sum of the charges f_ie of the resonators associated with the absorption, which arises from transitions of electrons in a given kind of orbit of the normal state of the atom, is equal to the sum of the charges of these electrons. One thus would have from (11) in the case of the inner electrons which give rise only to continuous absorption

$$\sum_j\int_{\omega_{nkj}}^\infty \alpha_{nkj}(\omega)d\omega\ =\frac{\pi p_{nk}e^2}{cm}\ , \tag{12}$$

where p_{nk} is the number of electrons in the atom in its normal state occupying n_k orbits. For the K-electrons $\alpha_k(\omega)$ according to various observers[9] is given by (10) with C_K about 0.02. This leads to a value

[11] W. Kuhn, Zs. f. Phys., *33*, p. 408; 1925.

[12] W. Thomas, Naturwiss., *13*, p. 627; 1925. See also F. Reiche and W. Thomas, Zs. f. Phys., *34*, p. 510; 1925.

for the above integral of about 0.025, while the right-hand side is about 0.05, p_K being equal to 2. The discrepancy between these values appears to indicate that the individual groups of electrons in the atom cannot be treated independently as regards the connection between their scattering activity at high frequencies and their absorbing properties.

The experimental data on refraction for an impressed frequency near one of the frequencies corresponding to an absorption edge are still too meager and too inaccurate to base any binding conclusions upon, especially so, since a large part of the refraction comes from the lightly bound electrons.

It may be remarked here that as regards the constants C_r in (10) corresponding to absorption edges which form a relativistic doublet some further information can be obtained from considerations similar to those applied by Heisenberg[13] for an explanation of the summation rules in multiplets. For when an atom is transferred by removal of an inner electron from the normal state to either one of two higher states forming a relativistic doublet, the initial state is the same in both cases. The total radiative activity of the final states too may be expected to be the same, for in both the number of electrons in the different n_k orbits is the same. This leads by the familiar argument to the conclusion that the ratio of the constants C of the two absorption bands, disregarding quantities of the order $\Delta\omega/\omega$, is that of the statistical weights j of the final states, a result arrived at by Stoner[14] in a different way.

4. THE NATURE OF THE COMPTON SCATTERED RADIATION

If the refracting medium is a light substance, and hard x-radiation be used, a considerable portion of the scattered radiation appears with its wave length shifted according to Compton's equation, the relative intensity of the shifted to the unshifted radiation increasing as the incident radiation is made harder, while the total amount of radiation is about what may be expected on the classical theory if all the electrons in the substance were free. This scattering, as is well known, is accompanied by recoil electrons. The question arises whether the shifted radiation, in the wave picture, must be considered as coming from the electrons undergoing recoil, the electrons thus affected radiating very strongly, or whether all the atoms must be considered as participating equally in its production, radiating weakly. In actual experiments

[13] W. Heisenberg, Zs. f. Phys., *31* p. 617; 1925.
[14] E. C. Stoner, Phil. Mag., *48*, p. 719; 1924.

carried out here on the index of refraction of carbon for molybdenum K-radiation, the intensity of the x-rays was at most of the order of magnitude 1 erg/cm²sec. As approximately 50 per cent of the scattered radiation is shifted, such an intensity would give rise to about 10^7 recoil electrons per cm³ per sec. Since the frequency of the incident radiation is about $4 \cdot 10^{18}$, and there will hardly be more than 10^6 waves in a wave train, the time during which an electron is engaged in a scattering process is not more than 10^{-12} sec. But if the shifted radiation came only from the electrons undergoing recoil, the above number of scattering processes would lead to the result that per cm³ at any time there are very few electrons or none at all engaged in this kind of scattering. The Compton shifted radiation could therefore not possibly contribute to the index of refraction by interference. Since, however, more and more of the scattered radiation becomes shifted radiation as the frequency increases, while at these high frequencies the index of refraction appears always to be what one would expect from the scattering of free electrons on the classical theory, it is evident that the shifted radiation, too, must in the wave picture be considered as coming from all the atoms, and that it must be coherent[15] with the incident radiation. This is a case similar to that of the resonance radiation in atomic gases and vapors. There, too, the question arises if this resonance radiation, in the wave description, is to be considered as coming from all the atoms, being completely coherent with the incident light, or whether at least part of it comes from atoms in the upper stationary state, emitting strong radiation with no phase relation to the primary waves. From analogy one may be inclined to adopt the former view.

This state of affairs is particularly suited to accentuate the difficulties which one encounters in trying to connect the wave description with the appearance of the elementary processes, in our case the production of recoil electrons. These difficulties are all the greater since the experiments of Geiger and Bothe[16] and of Compton and Simon[17] have made

[15] The shifted radiation can be considered, as far as the variation of its frequency with the angle of observation is concerned, as coming from sources moving in the direction of the incident beam with a velocity depending on the frequency of this beam (see A. H. Compton, Phys. Rev., *21*, p. 483; 1923). With coherence of the shifted radiation we mean that, if by a Lorentz transformation we go to a coordinate system in which the sources are at rest, then in this system the radiation coming from them has a definite phase relation to the incident waves. The fact that one does not observe selective reflection in crystals at angles corresponding to the shifted radiation does not contradict this, as the moving sources need not start moving all at the same time so that they no longer form a lattice.

[16] W. Bothe and H. Geiger, Zs. f. Phys., *32*, p. 639; 1925.

[17] A. H. Compton and A. W. Simon, Phys. Rev., *26*, p. 289; 1925.

it likely that giving up energy and momentum conservation in the individual processes, as suggested by Bohr, Kramers, and Slater,[18] is not a feasible way out of the dilemma.

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NEW YORK CITY.
JANUARY 29, 1926.

[18] Bohr, Kramers and Slater, Phil. Mag., *47*, p. 785, 1924; Zs. f. Phys., *24*, p. 69; 1924.

Instruments and Methods for locating Valuable Deposits.—This is an article which summarizes various methods by which information may be gained about various kinds of deposits underlying a region of the earth's surface. The author discusses first the instruments by means of which the gravitational field of the region may be mapped. Among the instruments mentioned are Sterneck's pendulum apparatus in which four half-seconds pendulums are used; and the torsion balance of Eotvos and its application are discussed. The second general method consists of the mapping of the magnetic field of the region and suitable apparatus for this purpose is described. Measurements of temperature and of radioactivity at various points of the region being explored are mentioned as methods of obtaining useful information. The second group of methods are the acoustic method of Fessenden and the seismic of Mintrop. Another method which appears to have given dependable results is that of burying electrodes at suitable locations and sending currents of audible frequency through the earth by means of these electrodes. By means of "potential seekers" or probes the equipotential lines between the electrodes may be mapped. This method will reveal both conducting and insulating deposits. In conclusion the behavior of deposits toward electromagnetic waves (absorption, reflection, effect of dielectric constant) is mentioned as a factor of which advantage may be taken. The author gives a tabulated summary of the various methods, indicating in this summary the apparatus, the quantities measured, the variations produced in these quantities by deposits, and finally the kinds of deposits to which the methods are applicable. (C. Heiland, Berlin; ZS. für Instrumentenkunde, *45*, pp. 417-436; 1925.)

PAUL E. KLOPSTEG.

The Measurement of Visibility with a Visibility Meter (Sichtmesser).—Estimation of visibility as modified by particles suspended in the air is usually accomplished in meteorology and navigation simply by observation with the unaided eye. In such an estimation the distance of visibility is given as the distance at which the observer is just able to distinguish an object. This method is convenient

but very inaccurate, since it is affected by large personal errors and since little is known about the factors which affect visibility. Unless such factors and the laws of their interrelations are known a prediction of visibility cannot be made. The author describes a visibility meter which may be designed either as a step-by-step instrument or as an instrument with continuous variation. It consists of a series of filters for producing "artificial turbidity" by filters of definite steps or by means of an optical wedge of increasing turbidity. Another form of instrument depends upon the fact that a frosted glass appears turbid because of diffusion of light, so that the apparent turbidity can be continuously varied by varying illumination of the glass by means of an iris diaphragm. The distance of the object used in sighting should be known within 3 per cent and its size should be at least .3 to .4°. The measurement consists of sighting upon the object through the eyepiece and rotating the disk carrying the filters or the optical wedge until the object viewed just disappears. A scale on the instrument gives the numerical equivalent of the visibility for the distance chosen. In the instrument employing the iris diaphragm the same manipulation leads to corresponding results. The author defines visibility as the reciprocal of the degree of optical turbidity of the air at unit distances, the unit being chosen as one kilometer or one nautical mile for practical purposes. If by distance of visibility that distance is meant at which the object will become just invisible, this distance can be computed from the value of the visibility by a simple formula. (A. Wigand, Halle; ZS für Instrumentenkunde, *45*, pp. 411-416; 1925).

PAUL E. KLOPSTEG.

Eye, Ear, Nose and Throat Manual for Nurses. By Roy H. Parkinson, M.D., Visiting Oculist and Aurist to St. Joseph's Hospital, San Francisco. 207 pages. C. V. Mosby Company, St. Louis, $2.25.

This manual represents the successful attempt of the author to present the salient facts regarding the anatomy, physiology and diseases of the eye, ear, nose and throat in such form as to be of practical value in the instruction of student nurses. The subject is covered simply and directly and the many illustrations add greatly to the pedagogical value of the little manual. The addition of the part on operating technic and the part on eye, ear, nose and throat problems as met by the Public Health Nurse serves to make the book useful not only to the student nurse but to the nurse specializing in eye, ear, nose and throat work and the Public Health Nurse as well.

D. F. SMILEY

THE RELATION BETWEEN DIFFUSE AND SPECULAR DENSITY*

By Clifton Tuttle

The influence of light-scattering by the developed silver grain upon the effective optical density of a photographic deposit is of considerable importance to both practical and scientific users of photographic materials. Density which is defined as $\log_{10}$ of (Incident flux)/(Transmitted flux) instead of being a definite property of the silver image is dependent upon the characteristics of the optical system of which it is a part. If the measuring instrument is so placed as to record only the flux transmitted in a direction normal to the plane of a light-scattering medium, the density value will be greater than for the case where the measurement is based upon the total transmitted flux. The first case which has been termed specular density ($d\|$) is the value which is of interest in dealing with images for projection—lantern slides, motion picture positives, and negatives for enlargement. The second case which is usually spoken of as diffuse density ($d\#$) is of interest in contact printing where negative and positive material are in juxtaposition and the total transmitted radiation is effective.

The dependence of density values upon the manner of measurement was the subject of an extended controversy between Hurter and Driffield and Abney.[1] Abney pointed out the effect due to light scattering. Hurter and Driffield agreed with the criticism offered by Abney but stated erroneously that scatter interferes only in plates of very high densities. Callier in his well known paper on the scatter of light by photographic materials[2] investigated a number of photographic emulsions and concluded that the relation between diffuse and specular density was approximately satisfied by the equation $d\| = Qd\#$ where the factor Q is a constant for a limited range of densities. Callier's measurements of diffuse density were made with the photographic material in contact with opal glass which was assumed to be perfectly diffusing. Under such conditions, the values he obtained would be true

*Communication No. 258 from the Research Laboratory of the Eastman Kodak Company.

[1] Jour. Soc. Chemical Industry, May and July, 1890.

[2] Phot. Journal, p. 200; 1909.

diffuse density values within the range of densities which he measured since here the effect of interreflection is negligible.

Renwick and Bloch[3] have shown that an equation of the exponential type fits Callier's data with greater accuracy than the linear function given by Callier.

It has been questioned whether diffuse density measurements give true contact printing density. Toy[4] found that diffuse density measured by the use of an opal diffuser must be multiplied by a constant factor to give true printing density. Bull and Cartwright,[5] however, found that an integrating sphere densitometer gave true contact printing density readings.

The photographic literature is replete with discussion of methods and instruments for density measurement and with treatments of the theoretical and practical aspect of the light scattering by turbid media. A detailed review and analysis of these papers is beyond the scope of the present work. Those engaged in photographic research are probably aware of the uncertainties arising from the use of different instruments employing light sources with varying degrees of collimation. On the other hand, many scientists who make constant use of the photographic plate as a measuring instrument appear to be quite unaware of its limitations in this respect. The magnitude of the difference between diffuse and specular readings in the data of the following investigation serve to emphasize the necessity for careful consideration of this property of photographic materials.

It is highly desirable at times to express one density in terms of the other, i.e., to evaluate contact printing density from measurements of projection density and vice versa. Such a case arose in connection with some work on tone reproduction with motion pictures in which it was desired to trace the reproduction of original object contrast through the steps of printing the negative by contact and projecting the positive on a screen. The measurement of negative printing density on a projection densitometer designed to measure positive projection densities simplifies the problem of locating corresponding negative and positive areas, and eliminates the possible error which might arise from the use of two different instruments. The purpose of the work reported here is to establish a relationship between diffuse and specular density for certain photographic materials.

[3] Phot. Journal, p. 49; 1916.
[4] Phot. Journal, p. 177; 1925.
[5] Phot. Journal, p. 180; 1924.

The projection densitometer used was designed to approximate the optical system of motion picture projection (see Fig. 1). Neither the incident beam nor the measured component is strictly parallel. It is interesting to note, however, that the deviation from parallelism was so slight that a check of this instrument with the bench photometer using collimated light showed no difference in density readings.

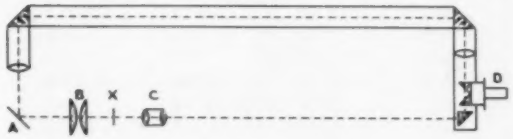

FIG. 1. *Projection Densitometer. A—900 watt monoplane filament lamp, B—5" condensing lens, X—photographic material, C—4½" projection lens, D—Martens polarization photometer.*

A form of integrating densitometer (see Fig. 2) was chosen to make the so-called "diffuse density" measurements because from its nature it actually measured the total transmitted light. This instrument makes use of the same Martens polarization photometer mounted in the same supporting unit as is used with the projection densitometer. The essential difference between the two instruments is in the measurement of transmitted flux.

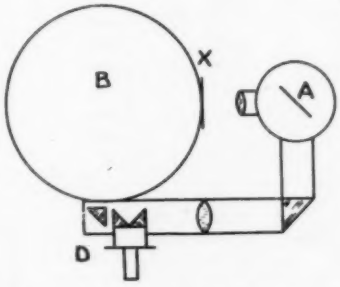

FIG. 2. *Integrating Densitometer. A—250 watt monoplane filament lamp, B—12" integrating sphere, X—photographic material, D—Martens polarization photometer.*

A number of densities ranging from .05 to 2.00 were prepared and measured on both instruments. Tables 1, 2, and 3 give the average of five readings for each density. Column 3 gives the ratio of specular to diffuse density—the Callier Q factor. Evidently a linear relation will not satisfy the data. The variation of Q is about thirty per cent.

The data seem to be very much better fitted by an exponential equation such as was sugested by Renwick and Bloch (loc. cit.).

TABLE 1. *Par Speed Motion Picture Negative*

$d\#$	$d\|\|$	$d\|\|/d\#$	$d\#$ calc.	e	T_s/T_t
.0641	.108	1.68	.0647	+ .94%	.095
.110	.180	1.64	.113	+2.8	.146
.223	.332	1.49	.220	−1.3	.228
.355	.509	1.41	.350	−1.4	.307
.460	.650	1.41	.457	− .66	.360
.550	.770	1.40	.549	− .18	.400
.640	.891	1.39	.644	+ .62	.450
.790	1.07	1.36	.785	− .64	.482
1.08	1.44	1.37	1.09	.92	.563
1.31	1.75	1.34	1.34	+2.2	.610
1.58	2.00	1.25	1.55	−1.9	.646
1.89	2.40	1.27	1.89	+0.0	.697

TABLE 2. *Motion Picture Positive*

$d\#$	$d\|\|$	$d\|\|/d\#$	$d\#$ calc.	e	T_s/T_t
.0484	.0697	1.44	.0483	− .21%	.046
.105	.152	1.44	.108	+2.8	.096
.230	.316	1.37	.231	+ .43	.180
.385	.523	1.36	.390	+1.3	.267
.438	.590	1.34	.442	+ .91	.288
.485	.651	1.34	.489	+ .82	.310
.565	.761	1.35	.575	+1.7	.343
.689	.902	1.31	.686	− .44	.391
.770	1.01	1.32	.771	+ .13	.423
.956	1.23	1.29	.946	−1.1	.477
.982	1.27	1.29	.978	− .41	.493
1.50	1.95	1.30	1.52	+1.3	.620

TABLE 3. *Eastman 40*

$d\#$	$d\|\|$	$d\|\|/d\#$	$d\#$ calc.	e	T_s/T_t
.0650	.101	1.55	.0631	−2.9%	.084
.113	.175	1.55	.115	+1.7	.125
.230	.332	1.44	.231	+ .43	.208
.553	.740	1.34	.553	0.0	.350
.940	1.23	1.31	.964	+2.6	.459
1.11	1.40	1.26	1.11	0.0	.486
1.24	1.53	1.23	1.22	−1.6	.510
1.35	1.61	1.19	1.29	+4.6	.520
1.41	1.75	1.24	1.41	0.0	.531
1.65	1.95	1.18	1.59	−3.6	.564

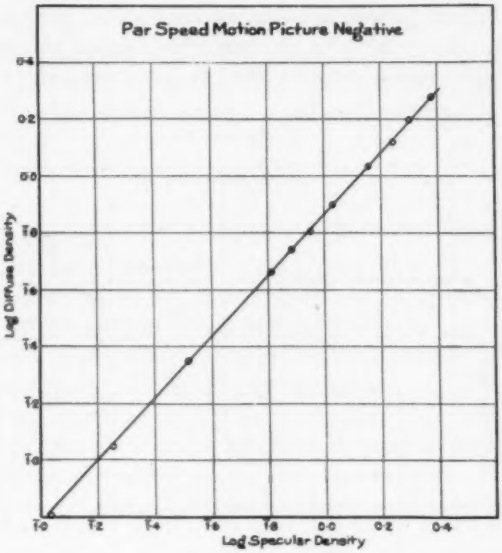
Par Speed Motion Picture Negative
Log Diffuse Density
Log Specular Density

FIG. 3

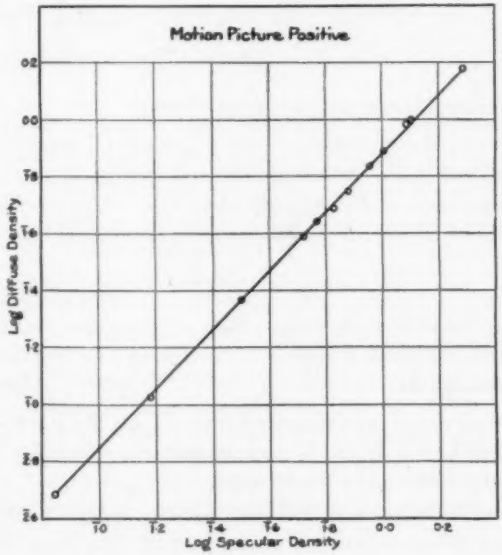
Motion Picture Positive
Log Diffuse Density
Log Specular Density

FIG. 4

Figs, 3, 4, and 5 show the data of Tables 1, 2, and 3 plotted logarithmically. A straight line represents the locus of the log $d\|$/log $d\ddagger$ values with a maximum error less than the error of measurement.

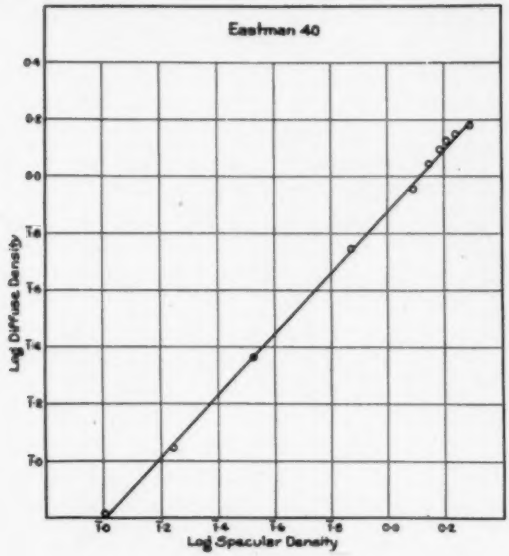

FIG. 5

The equation of these curves is of the form,

(1) $\log d\ddagger = m \log d\| - c$ or

(2) $d\ddagger = d\|^m / \text{antilog } c$

where m is the slope and c the intercept.

The values of these constants for the three emulsions investigated are as follows:

	m	antilog c
Par Speed Motion Picture Neg.	1.088	1.37
Motion Picture Positive	1.036	1.31
Eastman 40	1.091	1.30

The values of $d\ddagger$ as calculated from $d\|$ by the formula are given in column 4 (tables 1, 2, and 3) and the per cent difference between the observed and calculated values in column 5.

A number of samples of motion picture negative emulsion were developed for different times, varying gamma (the slope of the Hurter and Driffield characteristic curve) from .4 to 1.0 to determine the effect

of development upon the ratio of specular to diffuse density. It was concluded that the effect within this range was negligible. Three sets of motion picture negative densities representing three different batches of the same kind of emulsion were tested and the results were in very good agreement. It is doubtful, however, whether the constants m and c will hold with equal accuracy for all batches of the same emulsion since the average grain size differs slightly from batch to batch.

In column 5 of tables 1, 2, and 3 is given the ratio of scattered transmitted light to total transmitted light as determined from the density values. The increase of this ratio is practically constant with respect to decreasing transmission values from 100 to 30 per cent.

The relation of the scatter ratio to the density is not linear even for low values of density as was observed by Eggert and Archenhold[6] and therefore is not linearly proportional to the mass of scattering material present. It is possible that the scatter ratio may be some function of the perimeter of the interstices between silver particles, and it is hoped that by the use of single grain layers, some such correlation may be found.

EASTMAN KODAK CO.,
ROCHESTER, N. Y.
OCTOBER, 1925.

[6] ZS. f. Physikalische Chemie, p. 497; 1924.

Positive and negative ions resulting when electrons are projected into gases.—Electrons from a hot filament were projected with adjustable energy into a volume of gas (Hg, $HgCl_2$, I_2 or HCl) occupying a nearly equipotential region surrounded by metal sheaths and shields; one part of the walls of this region, however, was maintained at about one volt above or below the rest, so that the negative or positive ions would go to it; the electrons were prevented from reaching it by a magnetic field parallel to the initial direction of the electron-stream. The data show that positive ions occur only beyond a certain critical voltage of the bombarding electrons, but that negative ions are found at all voltages, being indeed more plentiful (per primary electron) the lower the voltage. Mercury is an exception to this rule, for which positive and negative ions appear at the same voltage. Nothing was noticed to indicate that an electron-impact may split a molecule such as HCl or $HgCl_2$ into two ions, one with an excess and the other with a deficit of electrons.—[F. L. Mohler (Bureau of Standards); Phys. Rev., (2) *26*, pp. 614–24; 1925.]

KARL K. DARROW

Electrons in the positive column of low-voltage arcs.—Experiments at Schenectady and Princeton with a probe immersed in the positive column of a mercury arc (or H_2, N_2 or Ar or Ne) show that as its potential is steadily lowered, the logarithm of the electron-current into it remains a linear function of the potential until the latter is so great that fewer than 10^{-5} of the electrons coming toward it can reach it; thus, that the Maxwellian distribution is valid to this extent. The mean energy of the electrons may correspond to a temperature as high as 50000°, being independent of current-density but increasing as the pressure is diminished. The atoms can not remotely approach this temperature as they collide with the electrons only a few times more often than with the walls of the tube. A probe, or a wall of the tube, charges itself to the potential at which the electron current and the ion current attaining it are equal; in a specific case of a Hg arc with the electrons at "temperature" 30000°, this potential will be -15.5 volts (referred to that existing in the arc); hence electrons with <15.5 equivalent volts of energy will in effect be specularly reflected from a wall, those with energy >15.5 will presumably be absorbed by the wall. One might therefore expect that a probe near a wall would indicate few electrons exceeding 15.5 equivalent volts in energy; yet what test experiments indicate is that the proximity of a wall, instead of suppressing the faster electrons, merely shifts the mean energy of the electrons somewhat downward while leaving the Maxwellian distribution unaffected. Another fact is, that the mean free path of the electrons in such an arc, computed as is done in the Drude theory of metallic conduction, comes out 5 to 10 times smaller than the values given by direct measurement (of the percentage of electrons in an electron-stream stopped by Hg atoms) or by the viscosity of Hg vapor. Measurements on the electron concentrations in an arc subject to a magnetic field (theory not stated) yield values of mean free path agreeing with those determined in the first-named way, not with those determined otherwise. The inference is: "the electrons in a mercury arc suffer many changes in momentum during the time that elapses between consecutive collision with atoms." —[I. Langmuir (Gen. El. Co.); Phys. Rev., (2) *26*, pp. 585–92; 1925]

KARL K. DARROW

Electrification by impact of Hg vapor against metal.—A stream of Hg vapor boiling in vacuo off from a small and continually renewed droplet, and striking against an iron plate a few mm distant and connected to a gold-leaf electrometer, sometimes charged the plate to more than 500 volts negative. The phenomena however varied in strange and unreproducible ways when the arrangement of the metal parts or the material of the target was varied.—[E. Perucca (Turin); ZS. f. Phys., *34*, pp. 120–30; 1925.]

KARL K. DARROW

THE UNIT OF PHOTOGRAPHIC INTENSITY

REPORT OF O. S. A. COMMITTEE ON UNIT OF PHOTOGRAPHIC INTENSITY*

INTRODUCTION

For the purpose of specifying the characteristics of photographic negative materials the factor of greatest importance is that referred to as "speed." In order to determine speed it is necessary to expose the photographic material under test to a light source of known intensity for a known time. One of the chief problems, therefore, in establishing standardized methods of plate testing is the adoption of an international unit of photographic intensity.

To those who are familiar with the present state of affairs in the measurement and specification of photographic characteristics, there is no need to emphasize the urgent necessity for agreement upon some definite standard light source for this purpose. For the sake of those who may not be entirely familiar with the details of this situation it may be well to give a brief résumé.

The method of measuring the characteristics of photographic materials which is in most common use at the present time, is that proposed originally by Hurter and Driffield in their classical researches on this subject which were published in the Journal of the Society of Chemical Industries in 1890 and 1891. Their system of speed measurement can be explained best by referring to Fig. 1. If a photographic plate is subjected to a series of different exposures there will be produced, when this plate is developed, a series of silver deposits differing in their light absorbing characteristics. The light absorbing power of such deposits is usually specified in terms of density, which is defined as the logarithm of the opacity, the opacity being the reciprocal of the transmission. Exposure is usually specified as the product of the illumination incident on the plate by the time of exposure. This is most commonly expressed in terms of meter candle seconds. If when the densities produced have been measured, they are plotted as a function of the logarithm of the exposure, a curve similar to that shown will be obtained. It has been found for the majority of materials that a relatively large proportion of this curve can be represented, to within limits of experimental error, by a straight line as shown in Fig. 1. If this straight line be extended until it cut the X-axis, the value of the exposure at the intersection point is termed the inertia, i, and speed was defined by Hurter and Driffield as the value obtained by dividing this inertia into 34.

The light source used by Hurter and Driffield was the standard sperm candle and this was used at a distance of 1 meter from the plate being tested. At that time the standard sperm candle was the standard of visual intensity and the illumination on the plate under these conditions was 1 meter candle. Exposures for the various areas of the plate were obtained, therefore, by multiplying 1 by the exposure time. It is evident, therefore, that the inertia is expressed in terms of meter candle seconds, the meter candle being the visual unit of illumination. This general method of measuring speed is that in common use at the present time.

Sensitivity of photographic materials to radiation of various wave lengths differ markedly from that of the human eye. For the ordinary blue-sensitive material the maximum occurs at

* This committee consists of the following members: E. C. Crittenden, Raymond Davis, and K. S. Gibson, Bureau of Standards; A. C. Hardy, Massachusetts Institute of Technology; L. A. Jones, Chairman, and C. E. K. Mees, Eastman Kodak Company; F. F. Renwick, DuPont-Pathe Film Manufacturing Corporation; and A. G. Worthing, Nela Research Laboratory. The Committee represented America at the Sixth International Photographic Congress held in Paris, July 1925.

a wave length less than 400 mμ, the extreme limit of the visible spectrum. From this point the sensitivity decreases rapidly for long wave lengths until at 540 mμ it is practically zero. For the human eye the sensitivity is a maximum at approximately 554 mμ decreasing at shorter and longer wave lengths to approximately zero at 400 mμ in one direction and 700 mμ in the other. It follows therefore that the speed obtained as outlined above, that is expressed in terms of meter candle seconds, will depend very much upon the spectral distribution of energy in the radiation emitted by the light source used. Thus, if sunlight is used instead of the light of the candle, the measurements of illumination made visually, and the exposure expressed in terms of meter candle seconds, the inertia value obtained on a given plate will be very much lower for sunlight than for the candle and hence the speed value obtained will be very much higher. The value of plate speeds obtained by various manufacturers and laboratories, therefore, depends entirely upon the distribution of energy in the spectrum of the light source which is used as a standard. At the present time in the testing of photographic materials a large number of different light sources are used. Among these may be mentioned the standard candle, the Hüfner, standard pentane, standardized acetylene flame, standard-

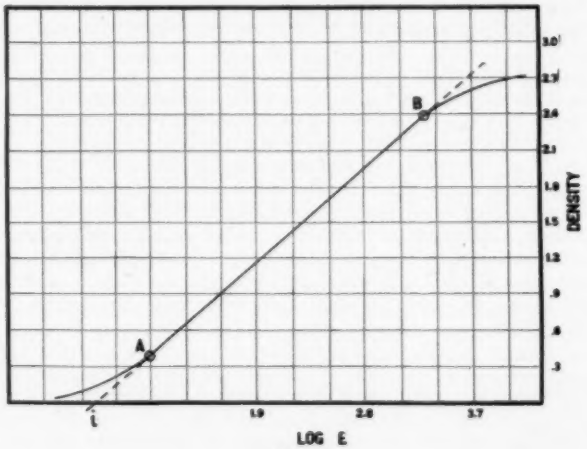

FIG. 1

ized incandescent lamps operating at efficiencies varying from 8 to 16 lumens per watt, and the standardized kerosene lamp. Since the exposure is always measured in terms of the visual illumination on the plate, it is obvious that these various standards result in a considerable amount of confusion. The trouble, however, does not end here. Photographic materials differ very much among themselves in spectral sensitivity, some being sensitive only to the wave lengths shorter than 540 mμ, others sensitized by special methods may be sensitive to all wave lengths shorter than 610 mμ, while still others are sensitive to the entire visible spectrum as well as to the ultraviolet.

The spectral distribution of sensitivity for three typical photographic materials is illustrated graphically in Fig. 2. The curves enveloping the white portions of the three spectrograms represent the relative spectral sensitivities for the three materials. These spectrograms were obtained in a wedge spectrograph using as light source an acetylene flame. The enveloping curves therefore represent the resultant of spectral sensitivity of the material and the spectral distribution of energy in the source. Since the same source was used in all three cases, however, the curves do represent relatively the distribution of sensitivity. The neutral wedge

used in this spectrograph is somewhat selective in the region of wave length shorter than 4800. The apparent decrease in sensitivity in the region between 400 and 4500 is therefore due to the absorption of the wedge rather than the absence of sensitivity in the materials. The short wave length end of these spectrograms should therefore be ignored. Independent measurements show that the sensitivity for all of these materials actually increases from 480 out to 400 mμ. The three materials illustrated in Fig. 2 do not by any means represent the maximum variation in sensitivity occurring in photographic materials. By special sensitizing methods the sensitivity can be increased in the direction of longer wave lengths out to 800 or even 1000 mμ. Such materials, however, are not used in large quantities and the spectrograms shown in Fig. 3 represent the great preponderance of commercial materials.

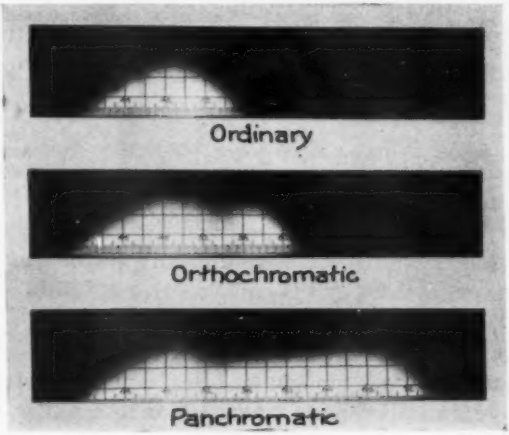

FIG. 2

It is evident if plate speeds be determined as outlined above, using for instance the pentane lamp which has a color temperature of approximately 1800°K, that a series of values will be obtained which are entirely different from the relative speeds of the same group of materials when used in the camera under daylight conditions. It is obvious, therefore, that some international agreement should be reached as to methods of measuring the speed of photographic materials in order to eliminate the very great apparent discrepancies between different manufacturers and laboratories.

The Sixth International Photographic Congress was held in Paris, July 1925. One of the problems which was considered by the Congress was the standardization of the methods used in testing photographic materials, and included in this was a consideration of the most suitable light source for adoption as an international unit of photographic intensity. This committee was appointed several months previous to the meeting of the International Congress and was instructed to study the problem and to prepare a report of its findings for submission to the Paris Congress. A meeting of the committee was held in Washington, D. C., February 3, 1925. At that time a preliminary survey of the problem was made and a tentative report drawn up. The discussion at that time indicated that further experimental data were needed and work to be carried out by the individual members of the committee was outlined. The results of this work had some influence on the report finally submitted to the Paris Congress. The text of this report containing the recommendations of this committee and the arguments submitted in support of those recommendations follows.

RECOMMENDATIONS

1. It is recommended that the unit of photographic intensity be defined as one visual candle power of radiation having a spectral composition, in the region between 350 mμ and 700 mμ, identical to that emitted by a complete radiator (black body) at a temperature of 5000°K.

2. It is recommended in the determination of speed, that the illumination incident on the photographic material shall be not less than 1.0 nor greater than 10.0 meter candles.

3. It is recommended that the exposure be non-intermittent and that the variation in exposure be produced by a variation of the time factor of exposure.

DISCUSSION

1. The primary object in the determination of the speed of photographic material is to obtain a knowledge of the relative exposures required to produce satisfactory practical results. The great majority of photographic materials are used in making pictures of objects illuminated by natural light, that is sunlight. Hence, values of plate speed should be determined by exposure to radiation having a spectral composition equivalent to that of the average outdoor illumination. It has been found that noon sunlight on a clear day at Washington, D. C., is practically identical in spectral composition to radiation from a complete radiator operating at a temperature of 5000°K. It is realized that the quality of sunlight varies appreciably with the latitude, altitude, time of day, weather condition, etc. The committee feels, however, that the radiation from a complete radiator at 5000°K approaches so closely to average sunlight as to be entirely satisfactory for adoption as a specification of the *quality* of the standard unit of photographic intensity.

Artificial sources, suitable for use as standards of intensity, operating at the required color temperature are not available. The tungsten incandescent lamp can not be operated much above 2500°K if long life as a standard of intensity is desired. The cylindrical acetylene flame has a color temperature of 2360°K. Plate speeds determined in terms of the radiation emitted by these low temperature standards are not proportional to the effective speeds of the materials when used in the camera for making pictures under natural illumination. This is especially true when color sensitive materials, orthochromatic and panchromatic, are included. The magnitude of the error arising from

the use of a low temperature source for measurement of speed is illustrated in Table 1. The values in the column designated as $1/i$ are reciprocal inertias obtained in the usual manner. The source used for obtaining the values in terms of a color temperature of 2360°K was the Eastman standard acetylene burner. The color temperature of this source was determined by the Bureau of Standards and by the Research Laboratory of the National Lamp Works. The source used for obtaining the values in terms of the 5000° quality was the acetylene flame mentioned above screened with the Wratten No. 79 filter. This screened source has been checked very carefully against sunlight by a photographic method and it has been definitely proven that the acetylene flame when screened with this filter gives results practically identical

TABLE 1. *Showing differential effects of spectral distribution of radiation upon the reciprocals of inertia ($1/i$) and upon the relative photographic speeds (RS) of photographic materials having different color sensitivities.*

Materials	Color Temp. of Source					F
	5000°K		2360°K			
	$1/i$	RS	$1/i$	RS	$\Delta RS(\%)$	
Ordinary	63	100	18	100	00.	3.5
Orthochromatic	42	67	17	94	+40.	2.5
Panchromatic	33	52	17	94	+81.	1.9

with those obtained by the use of actual sunlight. The photographic materials were chosen as representative of the various classes; that designated as *ordinary* being a high speed non-color sensitive plate, the *orthochromatic* material one of medium speed and good orthochromatic characteristics, and the *panchromatic* plate of the type having a relatively high sensitivity in the red and green regions. The values in the column designated as $1/i$ are in terms of visual candle-meter-seconds of radiation having spectral compositions as indicated by the color temperatures at the top of the table. These are shown as relative speeds in the columns designated as RS, the speed of the ordinary material being taken as 100 per cent in each case. In the column designated as ΔRS are shown the deviations resulting from the expression of speed in terms of the low temperature sources. It will be noted that the use of a low temperature source gives a speed value for the orthochromatic materials which is 40 per cent too high as compared with that of the ordinary plate, while the speed of the panchromatic material is 80 per cent too high when determined with the low temperature source. In

the last column of the table, designated as F, are given the factors by which the speed in terms of the low temperature source must be multiplied in order to obtain speed in terms of the 5000° source. It will be noted that the value of F varies appreciably for the different materials.

That the use of a standard operating at a relatively low temperature will introduce serious errors in the determination of plate speeds where color sensitive materials are concerned is commonly recognized. But it has been assumed, so long as measurements are confined to a group of non-color sensitive materials, that the low temperature source could be relied upon to give values relatively correct as compared with the speed values determined with sunlight. The data given in Table 2

TABLE 2. *Showing differential effects of spectral distribution of radiation upon the reciprocals of inertia (1/i) and upon the relative photographic speeds (RS) of photographic materials usually designated as ordinary or blue sensitive materials. None of these materials have any appreciable sensitivity for radiations of wave lengths greater than 550 mμ.*

Material	Color Temp. of Source					F
	5000°K		2360°K			
	$1/i$	RS	$1/i$	RS	$\Delta RS(\%)$	
A	63	100	18	100	00	3.5
B	63	100	15	83	−17.	4.2
C	50	79	18	100	+27.	2.8
D	46	73	16	89	+22.	2.9
E	44	70	14	78	+11.	3.1
F	23	37	8	44	+19.	2.9
G	10	16	4	22	+37.	2.5
H	3.5	5.6	1.2	6.7	+18.	2.9

indicate that the assumption is unwarranted. The photographic materials used are all classified as *ordinary* color sensitive. None of these materials show any appreciable sensitivity for radiation of wave lengths longer than 550 mμ and belong to the class commonly referred to as the *ordinary blue sensitive*. It will be noted from the values of reciprocal inertias that they vary widely in speed, A being a fast portrait type, while H represents the process type. In computing relative speeds, that of plate A is taken arbitrarily as 100 and the speeds of all the others expressed on this basis. The values in the column designated as ΔRS indicate again that the speeds obtained with the low temperature source are not proportional to those obtained with sunlight. For instance material B is 17 per cent too slow while G is 37 per cent too fast. The maximum variation found in this class of materials is of the

order of 50 per cent. It is felt that this demonstrates forcibly that it is quite useless to attempt to obtain speed values relatively correct from the standpoint of camera exposures by the use of a low temperature standard even when measurements are confined to materials of the so-called *ordinary* or blue-sensitive type.

Very little reliable information is available relative to the distribution of sensitivity in the near ultraviolet and it has been assumed in the past that photographic materials differed but little in this respect. Recent research on the spectral distribution of sensitivity of photographic materials indicates that photographic materials differ appreciably with respect to the distribution of sensitivity in the region of shorter wave lengths, 300 to 440 mμ. The results given in Table 2 may be explained by these differences in spectral sensitivity.

When this committee began its work it was suggested that all photographic emulsions containing no silver halide other than silver bromide would have the same spectral distribution of sensitivity regardless of the method by which the emulsion was made. If this were true such a material could be used as a standard photographic material by means of which to express the photographic intensity of a light source. Several such emulsions made by different methods and by different emulsion makers were, therefore, obtained. Determinations of speed were made using the 5000° and the 2360° sources and the results are given in Table 3. The relative speed of material *I* is assumed to be 100 for each of

TABLE 3 *Showing differential effects of spectral distribution of radiation upon the reciprocals of inertia (1/i) and upon the relative speeds (RS) of pure bromide emulsions made by different methods and by different emulsion makers.*

Material	Color Temp. of Source					*F*
	5000°K		2360°K			
	1/i	*RS*	*1/i*	*RS*	$\Delta RS(\%)$	
I	3.60	100	1.16	100	00	3.1
J	3.20	90	1.00	88	− 2.0	3.2
K	2.55	71	.94	82	+16.0	2.7
L	2.50	70	.75	66	− 6.0	3.3
M	1.76	49	.56	49	0.0	3.1
N	.74	21	.21	18	−14.0	3.5

the two sources and on this basis the relative speeds of the other materials are computed. In the column designated as ΔRS will be found the deviations of the speeds determined with the low temperature source from correct proportionality with those determined with the

5000° source. Using the low temperature source material K gives a speed value which is 16 per cent too high, while material N gives a value which is 14 per cent too low, the maximum variation in the group thus being approximately 30 per cent. Thus even in the case of pure bromide emulsions the low temperature source does not give values which are proportional to the speeds determined in terms of sunlight. We feel that the evidence presented demonstrates the futility of adopting an international standard of photographic intensity defined in terms of a low temperature source.

Methods are at present available whereby the sunlight unit recommended in this report can be realized with sufficient precision for practical needs. These involve the use of a low temperature source in conjunction with some type of selectively absorbing filter. Although the unit realized by these methods does not possess the characteristics of generality and reproducibility required for acceptance as an international standard, it does give results in agreement with practice and can be easily realized and maintained by any testing laboratory.

Colored glass and dyed gelatin filters are at present commercially available which have selectively absorbing characteristics such that when used with a source operating at a color temperature of 2360°K the radiation transmitted by the filter has a spectral composition approximately equivalent to that of noon sunlight or to a complete radiator operating at a temperature of 5000°K. Among such filters may be mentioned the following.

a. Wratten Light Filter No. 79 manufactured by the Eastman Kodak Company consists of dyed gelatin cemented between protecting sheets of white optical glass. This filter is deep blue in color and has a total visual transmission, for radiation of 2360° quality, of from 8 to 10 per cent. This filter is manufactured by the use of organic dyes and since these in general are not reproducible the filter itself cannot be said to be a precisely reproducible screen. It is manufactured, however, so as to conform to a very rigid standard, the limits of tolerance being very small. Its stability is excellent and filters which have been in use for many years show no measurable change in absorbing characteristics.

b. Several different types of blue glass are on the market which are used in conjunction with tungsten incandescent lamps for the production of artificial daylight. One of these, sold by the Macbeth Daylighting Co., Inc., has been examined photographically. Samples have been obtained which, when reduced to a thickness of 6 mm and used with a source operated at a color temperature of 2360°K, produces

light of a quality approaching closely to that of sunlight. This glass cannot be said to be a reproducible filter but by selection for color and by control of the thickness, filters of satisfactory characteristics can be obtained. Any well equipped standardizing photometric laboratory should be able to select and standardize filters of this type which would be entirely satisfactory for practical purposes.

c. Work has been in progress for some time in an effort to make a filter composed of solutions of stable and reproducible inorganic compounds. While complete success has not been achieved one filter has been made which approached fairly closely to the required characteristics. This consists of two elements, one of which is a 1 cm layer of 3 per cent solution of copper sulphate, and the other a 1 cm layer of a .5 per cent solution of copper sulphate to which has been added sufficient ammonia to completely convert the copper sulphate to ammoniacal copper sulphate. A filter made up in this way has a selective absorption such that a good approximation to sunlight quality is obtained. Relative speed values and color ratio values measured with this agree closely with similar values determined with actual sunlight. We do not feel that the use of this filter produces a radiation of spectral composition sufficiently close to sunlight to warrant its adoption as a standard method, but for practical purposes its use gives satisfactory results.

Further work is being done in an effort to obtain a stable reproducible filter of this type which will more closely fulfill the requirements and from the results already obtained we feel there is a probability of obtaining a filter of this type which eventually can be adopted as a standard.

All the filters mentioned above are designed specifically for use with a light source operated at a color temperature of 2360°K. This is a color temperature which is particularly convenient since it is given directly by the cylindrical acetylene flame. A standard acetylene burner made by the Eastman Kodak Company has been on the market for some years. This employs a steotite tip which gives a cylindrical flame approximately 50 mm high and 4 to 5 mm in diameter at the midpoint. This flame is enclosed in a cylindrical housing in one side of which is a re-entrant window approximately 4 mm wide. The limiting edges of this window are very close to the flame thus eliminating the parallax errors. Numerous measurements of the color temperature of the light emitted by this standard burner have been made by the Bureau of Standards, by the National Physical Laboratory, and by the Research Laboratory of the National Lamp Works. Results

obtained by these independent observers differ by only a few degrees and agreement has been reached on a value of 2360°K. In operating the burner it is only necessary to control the gas pressure and to take reasonable precautions as to the purity of the gas. Gas directly from a generator or from a cylinder of acetylene under pressure may be used. Variations in various factors have a relatively small influence on the color temperature and on the intensity of the standard source. The chief objection to the source is its relatively low candlepower which as manufactured at present is approximately 1.35.

Standardized incandescent electric lamps may be obtained from the national standardizing bureaus and from commercial standardizing laboratories. It is a relatively simple matter to operate these lamps at a color temperature of 2360°K by a proper control of the current. The candle power of such standards can be determined with the current adjusted to give the desired quality, 2360°K, and when these lamps are operated with the proper control of the current they form excellent standards of intensity and quality.

Thus the sunlight unit recommended in this report can be realized in practice by using either the acetylene flame or standardized incandescent lamps with any of the three filters described previously. It would seem that by using such light sources and filters properly standardized, either by the manufacturer or by the national standardizing laboratories, that a satisfactory realization of this sunlight unit can be obtained for practical purposes. We realize that none of the methods are of sufficient generality to merit adoption by an international congress. We feel that there is little doubt that a method of realizing the 5000° quality and having the requisite reproducibility and generality will be developed in the near future.

One other method for producing radiation of sunlight quality deserves to be mentioned. While but relatively little work has been done on this up to the present time it gives promise of being very reproducible and of sufficient generality to warrant its adoption as a precise method for realizing the sunlight unit. This involves the principle employed in the Aron's chromoscope and in the Leucoscope. The method is frequently referred to as that of rotatory dispersion and involves the use of polarizing elements such as nicol prisms and carefully cut quartz plates of definite thickness. A great deal of work has been done on the application of this method to other problems by

Mr. I. G. Priest.[1] A very clear idea of the method is given by the following quotation from Mr. Priest's paper.

"Light having a spectral distribution of energy closely approximating that of daylight (black body at 5000° abs., sun at the earth's surface or sun outside the earth's atmosphere) may be produced by passing the light from an artificial source (acetylene flame, vacuum tungsten lamp or gas-filled tungsten lamp) through two nicol prisms with a crystalline quartz plate between them, the path of the light being parallel to the optical axis of the quartz, and the thickness of the quartz as well as the angle between the principal planes of the nicols being properly chosen. If three nicols are placed in series in the beam, one quartz plate being placed between the first and second nicols and another quartz plate between the second and third nicols, the approximation to a desired spectral energy distribution may be made still closer."

In this paper specifications are given for producing radiation having spectral composition equivalent to that of black body at 5000° or sunlight at the earth's surface using either an acetylene flame of color temperature 2360° or gas filled tungsten lamps at different color temperatures as the primary sources of light. So far as we know apparatus of this type is not at the present time commercially available. It is probable that such equipment will be rather expensive to construct since a very high quality of workmanship will be required in making the various parts. The method however, appears to be promising and further work should be done with it for the production of a suitable international standard of photographic intensity. It is of considerable interest to note also that according to measurements by Mr. Priest[2] the radiation from a black body at temperature 5200°K is adequate to evoke the gray senstaion. In view of this fact it seems particularly desirable to adopt a unit having a spectral distribution approximating closely to that temperature as a standard for the photographic unit. Such a standard will then not only be equivalent to average sunlight but also practically identical to the subjective standard white.

2. Recent work which has been done on the failure of the reciprocity law indicates that the extent of failure is much less than had been previously believed. It has, however, been definitely established that

[1] Priest, I. G. A Method of Obtaining Radiant Energy having the Visible Spectral Distribution of a Complete Radiator at Very High Temperatures. J.O.S.A., p. 178, Marth, 1921.
Priest, I. G. Daylight (Artificial Production of) Phys. Rev. *2*, p. 502, 1918.

[2] Priest, I. G. The Spectral Distribution of Energy Required to Evoke the Gray Sensation. Sci. Papers Bur. Stand. No. 417.

such a failure does exist. In order to minimize errors in speed values which may arise if very low levels of illumination are used during exposure, the committee feels that it would be wise to fix limits of illumination between which exposures must be made.

The values proposed we feel will meet the requirements.

3. It has been definitely established that the photographic plate does not integrate intermittent exposures. Moreover the extent of the failure to integrate such an exposure varies widely with different materials. There is little doubt therefore that in the measurement of plate speeds the exposure should be of the nonintermittent type. In the construction of sensitometers it is much more convenient to obtain the required variation in exposure by control of the time factor than by a variation of the intensity. It seems desirable therefore to specify that the sensitometric exposure scale be upon a time basis. If the illumination limits specified in recommendation 2 be adopted there is little objection to the time scale of exposure.

ACTION AT PARIS

No official representative of the Optical Society was in attendance at the sessions of the Congress. One or two unofficial representatives from this country, however, were present. The report of this committee was given consideration but the recommendations as a whole were not adopted by the Congress. The report of the action taken follows.

SIXTH INTERNATIONAL PHOTOGRAPHIC CONGRESS

Provisional statement submitted to the members of the Permanent Executive Committee relating to the decisions taken at the conference of July 4, 1925.

N. B.—The statement of paragraph IV (measurement of density) has been left to the executive committee; the members of the committee are therefore invited to send their suggestions on this subject to the secretary of the committee: M. L. P. Clerc, 52 *bis*, Boulevard St. Jacques, Paris XIV°.

RESOLUTIONS

Section I—Sensitometry

General Regulations:

a. The resolutions adopted by the Congress will become effective only after a delay of six months, if no satisfactory improvement has been realized in this interval and if no serious objection has been presented.

b. A permanent executive commission comprising:
Belgium: M. A. Callier
Germany: Prof. R. Luther
France: A representative of the French Photographic Society
Great Britain: A representative of the Royal Photographic Society
United States: A representative of the Optical Society of America with, for sectetary, M. L. P. Clerc, shall decide on the adoption of the resolutions below as well as any modifications which may be found necessary.

I. STANDARD LIGHT FOR SENSITOMETRY

1. It is recommended to use, for sensitometric work, a light source of which the radiation is identical with that of a black body at 2360° (absolute).

The intensity of this source shall be expressed in candles: this intensity shall be measured visually by ordinary photometric procedure in comparison with the usual photometric standards.

2. In case it is considered necessary to use radiation representing approximately the radiation of a black body at 5000° absolute (average daylight day) there shall be placed before the light source provided in the preceding paragraph, a colored filter suitably chosen.

3. It is provisionally recommended to use for this purpose a filter composed of two distinct liquids, each of a thickness of 10.0 mm. One of these liquids shall be an aqueous solution of which 100 cubic centimeters shall contain 3.00 grams of pure crystallized copper sulphate $CuSO_4\ 5H_2O$ and 5 cubic centimeters of a solution of sulphuric acid containing per liter 50 grams of pure sulphuric acid reading 66° Baume. The other liquid shall consist of an aqueous solution of copper ammoniacal sulphate containing three times the quantity of ammonia necessary to give the compound $Cu(NH_3)SO_4$; 100 cubic centimeters of this solution should contain a quantity of copper corresponding to 0.50 grams of pure crystallized copper sulphate $CuSO_4\ 5H_2O$; this solution should not be prepared before use for less than a day nor more than a month.

The cell shall be made of three sheets of white polished glass the thickness of each sheet being not less than 2 mm nor greater than 4 mm. The cell used should be closed.

II EXPOSURE TO LIGHT

1. A non-intermittent sensitometer is recommended.

2. In view of the fact that convenient means do not exist at present for realizing a progression of exactly known intensities, without any

modification of the spectral composition, and that, if the intensity is maintained within suitable limits, the characteristic curves obtained, either by a variation of the time with constant intensity, or by a variation of the intensity and constant exposure time, are practically superposed, the Congress recommends the use of variable time, intensity being kept constant.

3. For emulsions intended for making negatives the intensity of the illumination falling on the sensitive surface shall be between 1 and 10 lux (meter-candles). For the study of the lower region of the characteristic curve an illumination of 0.01 lux (1/100° meter-candles) shall be used.

III. DEVELOPMENT OF THE NEGATIVE AND SUBSEQUENT MANIPULATIONS

1. An emulsion shall be tested, preferably, with the developer best suited to the purpose required such as the developer recommended by the manufacturer, the formula being specified in each case; it will also very often be desirable for the results to be indicated in terms of a standard developer; for emulsions intended for making negatives, the developer given below (without bromide) shall be used, a fresh solution being employed each time.

Formula to be chosen by the Committee:

- Water to make 1000 cc
- Sodium sulphite expressed Na_2SO_3 pure
- Para-aminophenol hydrochloride pure
- Sodium carbonate expressed as Na_2CO_3 pure

2. The temperature of the developer is to be $18°C \pm 0°.5$; the method of development should assure an effective agitation, this agitation being obtained otherwise than by bubbling of air or oxygen. Development should be carried on without previously wetting the emulsion. When development is carried on in a horizontal tray, the thickness of the liquid should be at least 1 cm.

3. The development shall be stopped suddenly by immersion of the negative either in weak acid, or in an acid fixing bath.

4. In the case of plates, before drying the plate should be treated with a bath of about 80 per cent alcohol.

IV. MEASUREMENT OF DENSITIES

1. The measurement of optical densities (decimal logarithm of the opacity) on negatives should be made by diffuse light, the image being placed against a sheet of plain parallel opal glass, ground on both sides.

(To be completed by the Committee)

From the total density at each point (the sum of the densities of the image and of its support) the density of the support is to be deducted, this being measured on a sample which has undergone the same treatment as the negative, except for exposure to light and development.

The density of the fog, measured on an unexposed portion of the negative, in proximity to the least exposed region of the latter, shall be specified for each time of development but shall not be deducted systematically from the densities of the image itself.

V. EXPRESSION OF RESULTS

1. It is recommended that authors always give at least the characteristic curves for three specified development times; these curves shall be plotted with the usual coordinates (D, $\log_{10}E$).

2. It is recommended that the limiting value of the development factor be always given.

3. The densities corresponding to low exposures (lower region of the characteristic curve) should be represented on a distinct graph, the curves being plotted in the coordinate system ($D.E$).

DISCUSSION OF THE RECOMMENDATIONS OF THE CONGRESS

It will be noted that in the first article, section 1, the Congress recommends for adoption as the unit of photographic intensity one visual candle power of radiation identical in spectral composition with that of a black body at 2360°. In the second article of the same section it recommends, "in case it is considered necessary," the use of a selectively absorbing filter of such characteristics that, when the above mentioned source (2360°K) is screened therewith, radiation of spectral composition approximately equivalent to that of a black body at 5000°K will be obtained. Apparently the existence of the "necessity" for use of the 5000° standard is left entirely to the judgment of the individual, laboratory, or manufacturer making the measurements, and doubtless this will in practice be determined largely by convenience or expediency. These recommendations fail to state specifically whether, when the filter is used the inertia is to be expressed in meter-candle-seconds computed from the luminous intensity of the unscreened source or in terms of the meter-candle-second computed from the effective luminous intensity of the source as modified by the absorption of the correcting filter. Presumably the latter was the intent of the Congress. The filter recommended provisionally by the Congress is to be made up according

to the formula (copper sulphate-ammoniacal copper sulphate) contained in the report submitted by this committee to the Congress.

The recommendations made by the Congress do not specify over what range of wave lengths the identity in spectral distribution between the proposed units and a black body at the specified temperatures shall exist. In the case of the 2360° source obtainable simply by an unscreened radiator perhaps such statement is unnecessary and it doubtless is more or less desirable that in case of both units the identity of spectral distribution should exist at all wave lengths. For the high temperature unit, however, such requirement is unnecessarily severe. From the standpoint of practical needs it would be entirely satisfactory if a wave length range from 350 mμ to 700 mμ were covered. In case of exposures made with a glass lens practically no radiation shorter than 350 mμ is transmitted. Moreover the atmospheric absorption is such that relatively little radiation of wave length shorter than 350 mμ reaches the earth's surface. On the other hand the spectral sensitivity of all photographic materials used to any extent in practice terminates at wave lengths of 700 mμ or less. We feel, therefore, that it would be wise to state specifically the wave length range over which approximation to identity of spectral distribution is required.

We can not refrain from expressing a feeling of disappointment in the action proposed by the Congress. We do not feel that the proposed action is wise nor that, if finally adopted, it will have the desired result of eliminating the present confusion in the determination of photographic speeds.

Actually the Congress proposes, as indicated by the sections quoted, the adoption of two distinct and unrelated standards for the same thing. It is obviously impossible to follow this course. No proposal of a method for expressing the magnitude of the 2360° unit in terms of the 5000° unit, or vice versa, is made. We do not believe any satisfactory method of doing this exists at the present time. When this committee began its work on the problem we hoped that the spectral sensitivity of pure silver bromide emulsions, differing in speed and method of manufacture, would be sufficiently constant so that such a material could be used as a standard photographic material (standard with respect to spectral sensitivity) in terms of which to correlate the photographic intensity of one visual candle power of 2360° radiation with the photographic intensity of one candle power of 5000° radiation. Our experimental results, incorporated in the report submitted to the Congress, show that this is not the case, the variation in the spectral sensitivity

of emulsions of this type being sufficient to cause a difference of ±15 per cent in the ratio of the two units. No satisfactory method of accomplishing the required correlation appears to exist. It seems therefore that a definite choice of one or the other of the two units proposed must be made.

The fact that the Congress made the recommendation relative to the 5000° unit is evidence that the necessity and desirability of expressing speeds in terms of exposures of sunlight quality was recognized. We believe that if speed values are to be of any practical importance they must be expressed in terms of a unit approximating as closely as possible the radiation to which the great majority of photographic exposures are made. We wish to reiterate that in our opinion the 5000° unit should be adopted, and in support of this conclusion present the following arguments.

1. *The great majority of exposures made on photographic materials for which the value of speed is the most important characteristic, are made to radiation of spectral composition approximating that of sunlight or a black body at 5000°K.* We have been informed that in the discussion of this question by the Congress the point was raised that a very large proportion of exposures made are on positive materials such as developing out papers, motion picture positive film, lantern slide materials, etc., and that for exposing these, sources of low color temperature (such as tungsten incandescent lamps operating at 2400°K to 2800°K) are almost invariably used. Therefore, since enormous quantities of such materials are used, it was contended that the 2360° source on the average is just as satisfactory as the 5000° unit. We should like to point out that in the case of the photographic materials mentioned *speed* is of only secondary importance, *contrast* and other characteristics being the determining factors in their use. As a matter of fact very little attention is paid to the speed of such materials. On the other hand in the case of negative materials speed is of utmost importance and it is for use in connection with negative materials that the unit under discussion is most urgently needed. Let us consider briefly the conditions under which photographic negative materials are exposed. Records show that approximately 100,000,000 feet of negative motion picture film are used every year. Practically all of this is exposed to sources of high color temperature. A large percentage of this material is actually exposed under natural lighting conditions both in studios and out-of-doors. In studios using artificial light the following sources are predominant: ordinary carbon arcs operating at color temperature of

approximately 4000°K; white flame and high intensity arcs operating at approximately 5000°K; Cooper Hewitt mercury vapor lamps in which the energy is emitted as a line spectrum and hence difficult to evaluate in terms of color temperature, but certainly of a very high effective color temperature since the radiation of short wave length is so relatively intense. The amount of motion picture negative exposed to low temperature radiation (high efficiency tungsten lamps operating at 3000°K or less) is negligible. It is evident, therefore, that for materials of this class speeds expressed in terms of the 5000° unit would be most useful.

Approximately 500,000,000 exposures are made annually on roll film, the average size being 3 1/4×4 1/4 inches. It is estimated that at least 95 per cent of these exposures are made under conditions of natural lighting. These two classes, motion picture negative and roll film, represent by far the great preponderance of photographic negative materials used. The next field in order of magnitude is probably the professional portrait work and here again the great majority of exposures are made in studios lighted by natural light, (sunlight or skylight). While some negative materials are used in other types of work the classifications mentioned above probably include 98 per cent of the total consumption and from a consideration of the light sources used there seems to be little doubt that a unit of high color temperature is desirable.

2. *Speed values based on the 2360° unit are not proportional to speeds obtained by using radiation of sunlight quality nor can any adequate conversion factor be defined.* Evidence for this is shown in Tables 1, 2, and 3 of the report submitted by this committee to the Congress. The materials represented in Table 2 are all of the ordinary blue sensitive (non-color sensitive) type. The distribution of spectral sensitivity of these materials is typefied by the first spectrogram in Fig. 2 given with the introduction to this report. It will be noted that a total variation of over 50 per cent is shown in the ratio of speeds determined by the two sources.

The unsuitability of the 2360° source is even more marked in the case of orthochromatic and panchromatic materials. This is shown in Table 1. The argument has been advanced that the relative proportion of panchromatic and orthochromatic materials used is so small that it is unnecessary to consider these materials in the adoption of an international unit of photographic intensity. The use of color sensitive materials during the past few years has been increasing at a very rapid

rate and it is probable that within a few years a very appreciable percentage of the total consumption of materials will be of the color sensitive type. We feel that it is unwise to neglect this possibility, and in adopting a unit at this time we should consider not only the present conditions but attempt to anticipate the future requirements.

If it be admitted that the reasoning in the previous section relative to the quality of light to which the majority of these materials is exposed, is sound, it follows that speed values based on the 2360° source would not be of any practical value, while those based on the 5000° source approximate very closely to the speeds of these materials as actually used.

3. *The 5000° unit can be realized with sufficient precision and reproducibility for practical purposes.* While it must be admitted that at the present time the 2360° unit may be realized more easily and with greater precision and reproducibility than the 5000° unit, the latter can be realized with sufficient precision and reproducibility for practical purposes. We feel that it would be much wiser to adopt a unit which is fundamentally correct, even though its reproducibility at present is not all that can be desired, than to adopt a unit simply because it is easy to realize and of great reproducibility but which we know will not give results of practical utility.

Any one of the three selectively absorbing filters mentioned in our report submitted to the Congress, when used with a source operating at a color temperature of 2360°K, affords a means of obtaining radiation approximating that of the black body at 5000° with sufficient closeness for practical purposes. A satisfactory test of the agreement between such screened sources and sunlight can be made by measuring the speed of a panchromatic plate or film through a series of color filters. For this purpose it is customary to use a red, green, and blue filter each transmitting a fairly narrow region of the spectrum. The performance of the correcting filters mentioned has been tested in this manner. The color filters used were the standard Wratten tri-color series: red No. 25; green, No. 58; and blue, No. 49. The results are shown in the following table.

Source	Filter	Relative Speeds		
		Blue No. 49	Green No. 58	Red No. 25
Sunlight		100	100	100
Acetylene	No. 79	100	90	107
Acetylene	Blue Glass	100	108	103
Acetylene	Liquid filter	100	95	88

It will be noted that the gelatin filter, No. 79, gives almost perfect agreement with the sunlight exposure; the blue glass also gives very good agreement; while the liquid filter is the least satisfactory of the three but good enough for practical purposes. We believe that the liquid filter by further experimentation can be greatly improved. Work on this is at present in progress.

There is little doubt that the other method mentioned in our report that of rotatory dispersion, will give even more satisfactory results than the filter methods. Work on this is also at present in progress although we do not have any final results to report.

In view of the fairly satisfactory approximate methods at present available for the realization of the 5000° unit and the very great probability of the development in the near future of a much more precise and reproducible method of obtaining the desired spectral quality, we feel entirely justified in recommending the adoption of the 5000° unit.

It will be noted by reference to the report of the Paris Congress published herewith, that the resolutions adopted are subject to a six months probationary period after which they will become effective provided no serious objection has been presented. We feel that the Optical Society should express an objection to the final adoption of the resolutions in their present form. Certainly it is unwise to attempt to establish two different standards for the same thing and a definite choice between the 2360° and the 5000° unit should be made. In view of our conviction that the 5000° unit is more desirable, and as a matter of fact will in time become absolutely necessary, we feel that it would be wiser to adopt the 5000° unit, even though it is somewhat difficult to realize with satisfactory precision at the present time, than to adopt the 2360° unit now and be faced with the necessity of abandoning it and going over to the high temperature unit in the near future.

OCTOBER, 1925

PHYSICAL OPTICS*

Report of Progress Committee for 1924-5

SPECTRAL STRUCTURES

Knowledge of spectral series and other regularities in line spectra was very completely compiled up to 1922 in three different treatises[1] which appeared almost simultaneously in that year. Since that time, however, a vast number of new spectral structures has been discovered, many of the very complex arc and first spark spectra have been partially—some almost completely—classified, and for some elements certain features of the higher spark spectra have been traced. These new data are rather widely scattered in the literature, and so far as we know, their compilation is not to be expected in the immediate future. This situation makes it difficult for anyone to gain a comprehensive grasp of the new material, and we are, therefore, attempting to give in this report a condensed summary of all spectral structures known at this date. It is felt that such a summary may be of interest and value not only to those who are actively engaged in the study of spectral structures, but may attract new workers in this fascinating subject by showing how restricted indeed our knowledge is even at the present time. For lack of space, it is not possible to give many details of spectral structures in this report; reference to the original papers will supply these.

The most important features of any spectrum may be represented by the two quantum numbers r and l, r indicating the maximum multiplicity of sub-levels occurring in spectral terms, and l expressing the type of spectroscopic term corresponding to the lowest energy. The well-known types of terms, S, P, D, F, G, etc., are represented respectively by $l=1, 2, 3, 4, 5$ etc., the new interpretation of l is discussed in more detail following Table 1.

The known facts concerning the structures of optical line-emission spectra are presented in Table 1, the first column of which contains the atomic number Z, the second the symbol for the element, and succeeding columns the quantum and reference numbers for spectra of

* The Progress Committee on Physical Optics for 1924-25 consists of the following members: K. T. Compton, Princeton University; L. R. Ingersoll, Chairman, University of Wisconsin; E. P. Lewis, University of California; W. F. Meggers, Bureau of Standards; and H. M. Reese, University of Missouri.

normal atoms (I) and of successive stages of ionization (II, III, IV, etc.). The numbers represent r, the superscripts l, and the numbers in parenthesis correspond to references at the end of this report.

TABLE 1. *Spectral structures*

Z	Element	I	II	III	IV	V	VI	VII
1	H	(1)						
2	He	$1,3^?$ (1,2)	(1)					
3	Li	2^1 (1)	(?) (2)					
4	Be	3^1 (1,4)						
5	B	2^1 (1)		2 (5)				
6	C	$1,3^?$ (1)	2^2 (6)	3 (5)	2 (5)			
7	N	2,4 (7)	1,3 (8)		3 (5)	2 (5)		
8	O	$3^2,5$ (1,9)				3 (5)	2 (5)	
9	F							
10	Ne	$1^1,3$ (1,10)						
11	Na	2^1 (1)						
12	Mg	$1^1,3$ (1)	2^1 (1)					
13	Al	2^2 (1)	$1^1,3$ (11)	2^1 (11)				
14	Si	$1,3^2$ (1,12)	2^2 (13)	$1^1,3$ (12)	2^1 (12)			
15	P	2 (13)		2 (5,14)	3 (5,14)	2 (5)		
16	S	$3^2,5$ (1,15)			2 (5)	3 (5)	2 (5)	
17	Cl		5 (16)			2 (5)	3 (5)	2 (5)
18	A	(1)						
19	K	2^1 (1)						
20	Ca	$1^1,3$ (1,17)	2^1 (1,18)					
21	Sc	$2^2,4$ (1,19)	$1,3^2$ (1,20)					
22	Ti	$1,3^4,5$ (21,22)	$2,4^4$ (22)					
23	V	$2,4^4,6$ (22,23)	$3,5^4$ (24)					
24	Cr	$3,5,7^1$ (25)	$2,4,6^2$ (26)					
25	Mn	$4,6^1,8$ (1,27)	$5,7^1$ (27)					
26	Fe	$3,5^2,7$ (28)	$4,6^2$ (26,22)					
27	Co	$2,4^4,6$ (29)						
28	Ni	$1,3^4 5$ (30)						
29	Cu	$2^1,4$ (1,31)						
30	Zn	$1^1,3$ (1)	2^1 (1,32)					
31	Ga	2^2 (1,33)						
32	Ge							
33	As	(34)						
34	Se	$3^2,5$ (1,35)						
35	Br							
36	Kr							
37	Rb	2^1 (1)	(36)					
38	Sr	$1^1,3$ (1,17)	2^1 (1)					
39	Yt	$2^2,4$ (37)	$1,3^2$ (1,38)					
40	Zr	$3^4,5$ (39)	$2,4^4$ (40)					
41	Cb	$4,6^2$ (41)	5^2 (42)					
42	Mo	$5,7^1$ (43)	$4,6^1$ (44)					

TABLE 1—*continued.*

Z	Element	I		II		III	IV	V	VI	VII
43	—									
44	Ru	5^4	(46)							
45	Rh	$4^4,6$	(46)							
46	Pd	$1^1,3,5$	(47)							
47	Ag	2^1	(1,31)							
48	Cd	$1^1,3$	(1,48)	2^1	(1,32)					
49	In	2^2	(1,33)							
50	Sn		(49)							
51	Sb		(34)							
52	Te		(35)							
53	I									
54	Xe									
55	Cs	2^1	(1)		(50)					
56	Ba	$1^1,3$	(1,36)	2^1	(1)					
57	La			1,3	(1,51)					
58	Ce									
59	Pr									
60	Nd									
61	—									
62	Sm									
63	Eu									
64	Gd									
65	Tb									
66	Ds									
67	Ho									
68	Er									
69	TuI									
70	Yb									
71	Lu									
72	Hf									
73	Ta									
74	W	$5^2,7$	(52)							
75	—									
76	Os									
77	Ir									
78	Pt									
79	Au	2^1	(1,53)							
80	Hg	$1^1,3$	(1,54)	2^1	(1,55)					
81	Tl	2^2	(1,45)		(55)					
82	Pb	$1,3^2,(?)$	(56)							
83	Bi		(34)							
84	Po									
85	—									
86	Em									
87	—									
88	Ra			2^1	(1)					
89	Ac									
90	Th									
91	Pa									
92	U									

Perhaps the first impression to be obtained from Table 1 is that it contains many gaps; little or nothing is known of spectral structures for the heavy atoms, and, except for some of the lighter elements, no classifications extend beyond the first spark spectrum. In spite of these shortcomings, however, some general laws of spectral structure and their relations to the periodic arrangement of the chemical elements are very strikingly shown in Table 1. It is seen that for arc spectra (I) even values of r occur for odd values of Z, and odd values of r for even Z. This is the general expression of the *alternation law* first suggested by Rydberg. The first spark spectra (II) have r even or odd with Z; they illustrate the *displacement law* of spectroscopy. Further regularities are shown, especially in the transition periods where there is a marked tendency for the r values to increase progressively and then decrease while the quantum numbers l for the first five elements of such a period are repeated for the next five elements.

The successful interpretation of spectroscopic data has gone hand in hand with the development of the quantum theory. Various semi-empirical rules which served as guides or criteria for the classification of spectra have been found to be expressible in terms of one or more sets of quantum numbers. In the report of last year[57] mention was made of Landé's theory of Zeeman effect and term structure of multiplets. This has since been verified in a remarkable and extensive manner by classification of spectra for which data on Zeeman effects exist.

A similar advance has recently been made with the theory of spectral line intensities. Sommerfeld's qualitative intensity rule, first refined in a limited way by the sum-rule of Burger and Dorgelo[58] has finally been extended to the exact computation of line intensities in multiplets[59] and the numerical relations have been verified to some extent by quantitative measurements of relative intensities of spectral lines.

THEORY OF SPECTRAL STRUCTURES AND OF THE PERIODIC TABLE

Without doubt, the greatest progress in the interpretation of complex spectra is to be based, as indicated by Hund,[60] upon the suggestions of Russell and Saunders,[61] of Pauli,[62] and of Heisenberg.[63] This extended theory is of such fundamental importance for the classification of spectra, and indeed for the understanding of the periodic table itself, that a brief summary of it may well be included in this report.

Since Kossel's and Sommerfeld's[64] paper on the Displacement Law, spectroscopists have been accustomed, in the alkali spectra, to derive

the azimuthal quantum number of the valence electron from the term character by means of the coordination

$$\begin{array}{cccccc} S & P & D & F & \ldots & \\ | & | & | & | & & \\ k = 1 & 2 & 3 & 4 & \ldots & \end{array} \qquad (1)$$

For the identification of the term character, and consequently of the k values, three criteria may be used: (1) the selection rule, (2) the multiplicity and inner quantum numbers of the term, (3) the Zeeman effect. The Zeeman effect certainly is the most powerful and unambiguous aid for finding the term character $S\ P\ D\ \ldots$ of even one single level because the magnetic splitting factor g of the level is a characteristic function of its k value.

In the last two years of rapid progress of spectral classification into the later columns of the periodic table these criteria—although derived for the alkalies and alkaline earths—have been somewhat carelessly applied to complicated spectra which are emitted by atoms with several (3 to 10) valence electrons—with the only exception that the selection rule (1), had to be replaced by a more general and flexible one.[65] As a consequence serious contradictions to Bohr's theory of the periodic table and electron-catching process were stated as the elements of the transition series Z = 19 to 38 and 37 to 46 were found to possess, in some cases, F terms as lowest levels (confirmed by absorption experiments), in others G or H terms with energies only slightly different from those of the normal state of the atom. Also in the spark spectra of the above mentioned elements the same difficulties were found; even in elements whose normal state had been found to be of D-type, the corresponding spark spectrum of the preceding element proved to have an F as the lowest term.

The way out of the dilemma was shown by an idea which was brought forward by Russell and Saunders[17, 61] in the special case of the "primed" terms of Ca, Sr, and Ba. This suggestion was generalized for any number of valence electrons by Heisenberg[63] and applied successfully to the spectra of the small and long periods by Hund.[60] According to these investigators, in atoms consisting of a rare gas core and several valence electrons the quantum number l which defines the empirical term character $S\ P\ D\ \ldots$ and which enters the Landé g-formula is not identical with the azimuthal quantum k of the last bound electron but is the quantized resultant of the k values of all valence electrons. It is obtained by the same formalism which, according to Sommerfeld[66]

and Landé[67] furnishes j as resultant of j_s and j_a or J as resultant of R and K. This may be illustrated for the case of two valence electrons (Ca, Sc^+, etc.) with the azimuthal quanta (angular momenta) k_1 and k_2. The l values of the terms which result from this particular pair of k vectors by different geometric addition are given by the following inequality:

$$(|k_1+k_2|-1) \geqq l \geqq (|k_1-k_2|+1)$$

(The terms -1 and $+1$, which seem to destroy the symmetry, result from using the conventional integer normalization of k instead of those by Sommerfeld or Landé.) If we assume the next to the last electron to be an S-orbit, which is the case in the spark spectra of Ca, Sr and Ba, the inequality gives

$$k_2=1\ , \qquad l=k_1$$

and we obtain the ordinary arc spectrum of the alkaline earths where the term character can still be identified with the k value of the last electron. The new idea shows its power when we assume the next to the last electron to be in a D orbit, (which corresponds to a very low metastable term in Ca^+, Sr^+, Ba^+ and very probably represents the normal state in Sc^{++}, Y^{++}, La^{++}). We get the following l values:

$k_2=3$,	$k_1=1$,	$l=3$
	$k_1=2$,	$l=4\ \ 3\ \ 2$
	$k_1=3$,	$l=5\ \ 4\ \ 3\ \ 2\ \ 1$

What we obtain now for Ca, Sr, Ba is essentially the system of primed terms. For Sc^+ the above scheme gives all the important terms of the spectrum; the D-term with $k_2=3$, $k_1=1$ represents the normal state of the Sc^+ ion. We now understand without difficulty the occurrence of F, G—etc. terms. For instance two orbits with the individual k values 3 will produce according to their orientation l values 1 to 5 which the spectroscopist will find as a group of five closely neighboring terms of S, P, D, F and G character. For several electrons the inequality must be modified in the following way. If we add an electron with the angular momentum k to an ion which is in a stationary state, corresponding to a quantum number l_+ and series system r, we obtain two sets of terms with the l values

$$(|l_++k|-1) \geqq l \geqq (|l_+-k|+1)$$

and the multiplicity $r+1$ and $r-1$. ("Verzweigung.")

For all these considerations we have tacitly assumed that none of the orbits which generate a term are so-called equivalent orbits, i.e., have equal total and azimuthal quanta, a case which is of great importance for the theory of the Bohr binding process and for our understanding of the closing of an electron-shell. Now a new principle, found by Pauli,[62] must be taken into consideration. It is well known that an elementary orbit is fully characterized by four quantum numbers n, k_1, k_2, m, or in another normalization n, k_1, m_1, m_2. Pauli's principle states that no two electrons are allowed to have the same values for all four quantum numbers. With the aid of this principle Pauli was able to account for the absence in the first member in the m^2S series of the alkaline earths and of the first members of the m^2S series of the earths.

These considerations reveal their fundamental importance when applied to the periodic system in a study of the evolution of a shell consisting of equivalent orbits. This has been done by Hund,[60] The manifoldness of values n, k, m_1, m_2, which an orbit n_k can have, is equal to $2\ (2k-1)=N$. This is also the number of magnetic levels. If we put two n_k orbits together, each of which has N possible quadruples of quantum numbers, then the number of possible arrangements which give the quantum numbers r, l and j of this two-valence electron spectrum, or the number of levels in a magnetic field, will be $N\ (N-1)/1 \cdot 2$. For, on account of Pauli's principle, the number of N^2 is reduced to this expression, which is known as the second binomial coefficient. For three equivalent orbits the number of combinations or the number of levels in the magnetic field is equal to the third binomial coefficient $N(N-1)(N-2)/1 \cdot 2 \cdot 3$, and so forth. We see that the number of possible magnetic levels and, therefore, the number of terms increases until the shell is half completed; then according to a well-known property of the binomial coefficient, this number decreases and finally becomes equal to 1. This means a term with inner quantum number zero; the atom has the momentum zero. Then the binding process for this shell is finished; the shell is closed.

The great success of these new ideas is that they not only predict the optical terms of the spectra of a shell but are also able to show the necessity for the existence of shells and, therefore lead to a complete theory of the *periodic system*. What is the length of a period; how many elements does a period contain? The number of elements is of course equal to the number of binomial coefficients, viz, N or $2\ (2k+1)$. Out of this we obtain as the number of elements in a shell of n_k-orbits, the values given in Table 2.

TABLE 2. *Number of electrons and elements forming closed shells.*

n_k	1_1	2_1	2_2	3_1	3_2	3_3	4_1	4_2	4_3	4_4	5_1	5_2	5_3
Electrons in sub-groups $N=2(2k-1)$	2	2	6	2	6	10	2	6	10	14	2	6	10
Element	He	Be	Ne	Mg	A	Zn	Ca	Kr	Cd	Lu	Sr	X	Hg
Z	2	4	10	12	18	30	20	36	48	71	38	54	80
Electrons in period $\Sigma 2(2k-1)=2n^2$	2	8		18			32						
X-ray symbol of shell	*K*	*L*		*M*			*N*				*O*		

This is the well-known system which E. C. Stoner[63] found empirically as best representing the facts of x-ray spectra. For the first time we are able to give theoretical proof for the number of elements in the different periods.

With the aid of these principles Hund has computed the terms in the spectra of the long and short periods. For the latter only a partial comparison with the spectroscopic facts is possible on account of incomplete investigation of these spectra. All the known terms are satisfactorily explained by the assumption that the two first electrons are bound in an n_1, all others in an n_2 orbit. But for the complicated spectra of the metals in the long period ($Z=19$ to $Z=28$) which have been extensively investigated a complete check of theory and empirical facts is possible.

Hund found that all the low terms characterizing the spectrum of an element with atomic number $Z=18+z$ can be accounted for by electron configurations of three kinds:

(1) $z-2$ orbits of 3_2 and 2 orbits of 4_1 type
(2) $z-1$ orbits of 3_2 and 1 orbits of 4_1 type
(3) z orbits of 3_2 and 0 orbits of 4_1 type

The normal state of the atoms K, Ca, Sc, Ti, V, Mn, Fe, Co, Ni and Zn belong to configuration (1) whereas (2) and (3) give metastable states. The normal state of Cr and Cu and of all the singly ionized atoms correspond to (2) and it is very probable that the normal states of the doubly ionized atoms and of all the higher stages of ionization belong to configuration (3.) With this remarkably simple result all the difficulties in reconciling the empirically found lowest terms of some of these elements with the Bohr theory of the periodic table vanish. Also the puzzling

decrease of multiplicity of the terms towards the end of the shell (Fe, Co, Ni) is understood without any additional hypothesis (because the binomial coefficients decrease!).

Another consequence of this new theory is concerned with x-ray spectra. Since the last binomial coefficient is equal to the first and so on, we are led to the law that a closed shell with one electron has the same character and lowest term as a closed shell which has lost one electron, i.e., which is simply ionized. This theorem has been formulated by Wentzel and proved by Pauli. The x-ray terms represent, according to Kossel, such singly ionized shells and, therefore, must have doublet character like the terms of the alkalies and ionized alkaline earths. This is indeed a well known fact, to which attention has been called by Grotrian, Landé, Millikan and others.

SPECTRAL INTENSITIES

(a) *Multiplets and Zeeman Components.* The first suggestion in this field was Sommerfeld's intensity rule[69] according to which, in any multiplet, those lines are strongest in which the azimuthal and inner quantum numbers (k and j) change in the same sense and the weakest lines are those in which they change in the opposite sense. This was put on a quantitative basis by Ornstein and his collaborators,[70] and may be stated thus: "In any multiplet, the sum of intensities of lines which have the same initial state is proportional to the statistical weight of that state, and similarly the sum of intensities of lines with the same end state is proportional to its statistical weight." These statistical weights are equal to $2J$, where $J=j$ for systems of even multiplicities and $J=j+\frac{1}{2}$ for those of odd multiplicities. This rule gives a unique solution of the intensities only for doublet systems where the azimuthal quantum number changes by one unit. For instance, for a diffuse doublet of an alkali metal we have three lines of intensities as shown within the square.[71]

By Theory

	j		d: 3	2	
		$2J$	6	4	
p	2	4	9	1	10
p	1	2	0	5	5
			9	6	Sum

By Experiment

		d: 6	4	
	$2J$			
p	4	100	12	112
p	2	0	60	60
		100	72	Sum

Similarly, for a diffuse triplet, as of Ca.

			d		
j		3	2	1	
	2J	7	5	3	
p 2	5	63	u	12-u	75
p 1	3	0	45-u	u	45
p 0	1	0	0	15	15
		63	45	27	Sum

		d			
	2J	7	5	3	
p 5		100	18	1	119
p 3		0	54	19	73
		0	0	25	25
		100	72	45	Sum

Here the theory leaves undetermined a quantity u, but the experiments conform to the "sum" rule.

Numerous papers have dealt with attempts to extend these ideas to Zeeman components (the number of which is $2J$ for any multiple term) and they have been expressed both in the notation of Landé and of Sommerfeld.[72] Kronig,[73] Sommerfeld and Hönl[74] and Russell[75] have independently generalized the "sum" rule making it applicable to all known types of multiplets, and Russell has shown that this generalization agrees, within accuracy of experimental data, with all known data on multiplet intensities. Russell obtains for a multiplet of "ordinary" type an expression for the intensity of any component given by the three equations

2J						
	x_l	y_l	z_l			
		x_l	y_l	z_l		
			x_l	y_l	z_l	
				—	—	—

$$z_l=\frac{R}{8}\left(1-\frac{l}{2K+l}\right)\{(4R^2-l^2-1)^2-4l^2\}$$

$$y_l=4RK^2(4R^2-l^2)-z_{l+1}-z_{l-1}$$

$$x_l=z_l+4RK^2(8K^2+4Kl-4R^2+l^2-1)$$

where $2R$ is the multiplicity, i.e., 1, 2, 3, etc., for singlet, doublet, triplet, etc. terms; $2K$ is the maximum number of components which a term of a given series can have, so that $K=k-\frac{1}{2}$ where k is the azimuthal quantum number; $J=j$ for systems of even multiplicity and

$J=j+\frac{1}{2}$ for those of odd multiplicity, where j is the inner quantum number; l is the value of a subscript defined* by $l=J_1+J_2-2K$ when $K>R$ or by $l=J_1+J_2-2R$ when $R>K$. Corresponding expressions are found for other types of multiplets, such as "rhomboid" and "symmetrical" types.

(b) *Line Intensities.* The theory of line intensities is a product of the Correspondence Principle, according to which the intensity of any line, resulting from the transition of an electron between two stationary states, should be proportional to the square of the amplitudes of the corresponding harmonic in the periodic motion of the electron, averaged in some way over its initial and final (and probably intermediate) states. To do this, attempts have been made to calculate the shapes of the electron orbits in certain cases where they are probably most nearly Keplerian, thence to find the Fourier series expressing this motion, and to find the amplitude of that harmonic which corresponds to the emitted light (has the same frequency). To do this, certain reasonable assumptions are made regarding legitimate approximations (a) when the electron is far outside the atomic residue and (b) when it is within the atomic residue.

An uncertainty exists as to what sort of average to take of squares of amplitudes in the states involved. Hoyt[76] has formulated and discussed six possibilities, which have been further treated for very simple cases by Tolman.[77] In general an arithmetic or a logarithmic average works best, but no general rule is as yet available, since one works better in one case and another in another.

Mention should be made of work of Bartels,[78] who used the Fues models of alkali atoms and calculated for a number of s and p states of sodium the orbital dimensions, the transition probabilities and the average duration in the excited state.

It is certain that great developments will come in this field with the perfection of experimental technique. Significant in this line is the wide use of the Moll recording microphotometer, and the fine work of Harrison[79] and Slater,[80] who have strikingly verified the predictions of Hoyt.

(c) *Band Spectra.* In this field, intensities have been considered by Kemble,[81] who showed that intensities of HCl bands agree best with experiment if the "weight" is taken to be the mean of that in initial and final states, which is justified by treating the molecule as a non-

* This symbol l must not be confused with the quantum number l defined on page 587.

degenerate system (as if in a magnetic field) and then calculating the intensities as the Zeeman components are allowed to coalesce. Dieke[82] has applied the "sum rule" of Burger and Dorgelo[70] to band spectra and obtained expressions for intensities of components of the P and R branches of bands of the simple Deslandres type, and for certain cases where the bands have a fine structure. The experimental data are inadequate to test these conclusions.

QUANTUM VS. WAVE THEORY

Two striking attempts have been made to reconcile quantum and wave theories, both naturally involving some rather radical departures from our customary ideas. The theory of "virtual oscillators" suggested by Slater[83] and Bohr, Kramers and Slater[84] has been developed by Slater[85] formally to account for a wide range of optical phenomena. The fundamental idea is that atoms continuously emit and absorb radiation in waves without regard to the principle of conservation of energy (which is taken to be only statistically true), that these atoms do not change energy while radiating, but that they do change energy discontinuously when changing their stationary states. Furthermore, this radiation is emitted not as a consequence of the transition, but as a result of being in the stationary state, and all frequencies are radiated and absorbed which would be involved in any possible transition on the ordinary Bohr theory. Thus transitions act in changing the group of frequencies which an atom absorbs and emits.

The second theory is that of L. de Broglie,[86] which assumes the existence of a periodic phenomenon, associated with energy and mass as given by the relativity relation between energy and mass. The phase of this phenomenon is supposed to travel with a velocity greater than light. A proportionality exists between the "four vector" impulse of a material particle and the corresponding vector representing the propagation of this wave. Fermat's principle applied to the wave is identified with the principle of least action applied to the moving particle. These ideas are applied to the periodic motion of an electron in a Bohr atom and lead to expressions for the quantized stationary states. Various applications are suggested, among them scattering of x-rays and Planck's laws of radiation.

These two attemps are probably too speculative to satisfy the mind of the average physicist, but it is hoped that they may lead toward a rational and, if possible, simpler viewpoint.

On the other hand are recent experiments of Bothe and Geiger[87] and of A. H. Compton and Simon[88] which seem to give direct experimental proof of the existence of individual radiation quanta possessing energy $h\nu$, momentum $h\nu/c$ and reacting like particles at collisions with electrons. Bothe and Geiger found a simultaneity between the production of a scattered x-ray and an accompanying recoil electron, and Compton and Simon actually took stereoscopic cloud expansion photographs of the tracks of the incident quantum, scattered quantum and recoil electron at individual scattering acts and proved the applicability of the laws of impact between mass particles. These results are believed fatal to the theory of Bohr, Kramers and Slater, at least in its present form, and support what is usually considered the most extreme form of quantum theory,—the energy quantum theory of Einstein.

SPECTRAL SERIES AND ATOMIC STRUCTURE

Attempts are being made to interpret the constants of the Ritz formula in terms of atomic structure, and with considerable success in view of the approximations which are necessary. Schrödinger[89] has discussed "hydrogen like" spectra (those due to transitions between states well outside the atomic residue). He accounts for the constants of the Ritz denominator by the shielding effect of the inner electrons and the polarization of the atomic residue produced by the field of the series electron. He finds, on comparison with spectral data, that the polarization is nearly constant for a given series, but that there are surprising differences in different series. This he believes is due to a certain degree of resonance motion of the nucleus at certain frequencies. This work is a development of earlier work by Born and Heisenberg.[90]

Lindsay[91] has calculated the orbital dimensions, quantum defects and effective quantum numbers for a series of stripped atoms of similar electronic structure, Na, Mg^{+}, Al^{2+}, Si^{3+}, P^{4+}, S^{5+}, Cl^{6+}, and obtained results in fairly good agreement with spectroscopic data, departing in a direction to be explained by polarization of the atomic residues.

Wentzel[92] has made an exhaustive analysis of effects of screening, penetration into atomic residue and relativity on the orbits of series electrons and has concluded that best agreement is obtained if the energy of any term n_k is expressed as usual for the part dealing with the relativity correction, but the non-relativistic part is replaced by an average value between $k-1$ and k. This leads to the same result as does Sommerfeld's method for hydrogen atoms, and gives accurately the separation of the screening doublets and the screening constant of the relativity doublets.

It was formerly believed that x-rays are produced only by electron transitions from a normal orbit to an inner, temporarily vacant, orbit, —as opposed to optical lines which are produced by transitions from virtual orbits. L. de Broglie and Dauvillier[93] and Bäcklin, Siegbahn and Thoraus[94] have discovered evidence of such "optical" lines in x-ray spectra, i.e., lines due to transitions from orbits which are known normally to be unoccupied. These lines are especially prominent in spectra of light elements and of elements in the transition groups of the periodic table, in which there are outer electron shells which are incompleted. Such lines are detected by their falling somewhat out of line with the others on the Moseley curves.

In continuance of their work on series relations between spectra of stripped atoms, Millikan and Bowen[95] now offer the following suggestion regarding the dilemma, which their experiments have created, i.e., the fact that regular and irregular doublet laws are valid throughout the continuous range from x-ray to optical spectra, whereas different explanations have hitherto been given for them in the two fields. In the x-ray region the doublets are nicely explained as due to different shapes of orbits, involving differences in shielding and relativity correction, whereas in the optical region there is good reason for ascribing the multiple energy states to differences in orientation of series electron orbits with respect to the atomic residue. Rather than abandon either of these explanations, these authors suggest that it is preferable to suppose that orientation differences lead to formulae of practically identical type with those derived from relativity, although the method of deriving such formulas is still obscure. This amounts to preferring a surprising accidental coincidence to the giving up of either of the two strongly intrenched theories.

An entirely different attempt to solve this dilemma has been made by Heisenberg in connection with his theory of the complex structures of spectra by atoms with several valence electrons. The reader is referred to the section on "theory of spectral structures and of the periodic table" on p. (590).

OTHER EMISSION PROBLEMS

Band Spectra and Isotopes. Joos[96] has reviewed the subject of isotope effects in spectra and pointed out that these effects are quite satisfactorily accounted for in band spectra, by the effect of isotope mass on moment of inertia of the molecule and hence on the separation of the band components. In line spectra, on the other hand, the predicted

effect on the Rydberg constant is extremely small and has not been detected certainly in any case except in lead, and in this case, the effect is too large and seems to require an additional factor in its explanation.

By far the most important work in this field is described in a recent series of three papers by Mulliken,[97] in which are considered: I, theory of band spectra; II, isotope effects in band spectra of $B^{10}O$ and $B^{11}O$; III, isotope effects in band spectra of $Cu^{63}I$ and $Cu^{65}I$. These papers also contain energy level diagrams and much interesting information about bands which is incidental to the main topic.

A review of band spectra in general, together with a bibliography of the subject up to this year, has been published by Mecke.[98]

Polarization of Resonance Radiation. The effect of magnetic fields on the polarization of resonance radiation, discovered about two years ago by Wood and Ellett, is generally accounted for by the Larmor precession of the excited atom about the direction of the magnetic field. Among the interesting developments of this discovery may be mentioned the following recent work:

Ellett,[99] with improved technique to avoid the depolarizing action of neighboring atoms at high vapor pressures, has investigated the polarization of the resonance radiation as affected by various orientations of the magnetic field, and has found that none of the theories thus far proposed are adequate to explain the phenomena. The polarization decay constant is given in terms of the ratio of the actual separation of the Zeeman components to the classical value. Incidentally, the experiments give $\tau = 1.35(10)^{-8}$ sec. as the mean life of the excited state.

Breit[100] has worked out the theory of these experiments on the assumption that the excited atoms may be treated as isotropic harmonic oscillators.

A new mode of attack has been reported by Fermi and Rassetti.[101] By applying magnetic fields of one gauss, the frequency of the normal Larmor precession is $1.4 \cdot 10^6$. These investigators studied the polarization in alternating magnetic fields of about one gauss and of frequencies up to 10^7 and found results which indicate that the actual Larmor precession for mercury atoms excited to the $2p_2$ state is 3/2 the normal value, agreeing with the fact that the Zeeman separation of $\lambda 2536$ is 3/2 the normal value.

Still other lines of attack are two by Gerlach and Schütz,[102] who employed two methods for estimating the mean life of the excited state of Na(D) and Hg(2536). In the first method they interpreted Wood's

result that Na vapor, excited by D_1 light, emits both D_1 and D_2 at high vapor pressure and only D_1 at low vapor pressure. This difference was ascribed to the effect of collisions at high vapor pressures, which are too infrequent to be effective at lower pressures. The life of the excited state is thus compared with the mean free time between collisions. In the second method the depolarizing effect of collisions on polarized radiation in a magnetic field permitted a comparison between the life of the excited state, the period of the Larmor precession and the mean free time between collisions,—according to conditions.

Collisions of Second Kind. Several obscure or newly discovered spectral phenomena seem likely to be explained as due to excitation by excited atoms of a different type. Among these may be mentioned the "auroral" green line, which McLennan and Shrum[103] (see also later discussion) have electrically excited in oxygen admixed with large amounts of helium or neon; the newly discovered arc lines of N by Merton and Pilley[104] and Kiess[105] in mixtures of nitrogen and helium and explained on the basis of collisions of the second kind by K. T. Compton[106]; the comet tail spectra found by Lemon[107] to be brilliantly developed in helium containing traces of carbon compounds, probably oxide; the identity in the spectra of chemiluminescence and fluorescence found by Kautsky and Neitzche[108] and interpreted as due to the transfer, in chemiluminescence, of energy from the reacting to non-reacting radiating molecules. These results are all suggestive of the possible importance of this phenomenon, which has but recently been discovered.

A different aspect of these collisions is the quenching of resonance radiation by collisions of the second kind with admixed gases. Stuart[109] found that molecules of H_2, O_2, CO are practically 100 per cent efficient in preventing by a collision the resonance radiation of an excited Hg (2536) atom, whereas air, CO_2, H_2O, N_2, A, He were less efficient in the order named. (Helium is but 0.3 per cent efficient.) Also the kinetic theory radius of an excited mercury atom was found to be about three times that of a normal atom.

Miscellaneous. The problem of molecular structure has been attacked by Hund[110] in the case of polar multiatomic molecules. The central force as a function of distance is found from data of the band spectra. Thence are calculated the equilibrium arrangements of the atoms, the molecular dimensions, the heats of dissociation and the residual chemical affinities of the following systems: H_2O, HO, H_3O, NH_3, H_2S, H_2Se, NaOH, KOH. Probably a combination of such considerations with molecular electric moments would lead to still closer approximations.

Harrison and Forbes[111] have rendered a valuable practical service to investigators who have occasion to use mercury arcs as illuminants and desire to know the absolute or relative energies emitted in various parts of the spectrum. Numerous curves give these intensities for a variety of working conditions, i.e., current density, potential drop and vapor pressure in the arc.

PHOTOELECTRIC EFFECT

There are many titles in this field but only a few can be mentioned. Of special interest is the activity shown in measuring the effect in vapors. Lawrence[112] has measured the photoelectric effect in potassium vapor by a method similar to that of Williamson.[113] He finds a fairly sharp long wave length limit at 2610A, considerably shorter than that determined by Williamson, whose results indicated substantial agreement with the Bohr theoretical value of 2856. In explanation of his disagreement with this value, Lawrence suggests the possibility of the vapor being molecular in character instead of atomic. If an energy of .4 volt is assumed as required for dissociation, this, added to the 4.3 volts required for ionization gives 4.7 volts, corresponding to the quantum of wave length 2610A, his observed threshold value.

Rouse and Giddings[114] have repeated Steubing's[115] work on the ionization of mercury vapor by mercury light, with improved technique. The uncertainty in distinguishing between photoelectric effects from the electrodes and volume ionization in the vapor was avoided by making the area of one electrode several times that of the other. The photocurrents drawn from each electrode in turn and due to the action of the scattered light on the electrodes would then bear approximately the ratio of these areas, while the volume ionization of the vapor would give a current very nearly independent of the area of electrode to which the positive ions were driven. Using a hot mercury arc as a source of light, no effect other than could be accounted for by photoelectric action on the electrodes was found; but with light from a water-cooled arc—containing the core of the line 2536—currents a hundred-fold larger were obtained and found nearly independent of the direction of the driving field.

Since, according to quantum theory, there is no single wave length present in the exciting light of sufficient energy to ionize, some sort of cumulative action must occur. The possibility that the energy comes from the 2536 line and some $2p_2$ line which the atom, already excited by the 2536 light, is in condition to absorb was largely eliminated by

tests in which the $2p_2$ lines were cut out of the exciting light. Other possible explanations have been considered and tested, but with no very definite results. This seems to be a new and interesting type of ionization process and its study is being continued.

Foote and Mohler[116] have measured the photoelectric ionization of caesium vapor using the ingenious device of Kingdon[117] whereby the positive ions produced travel in comet-like orbits about a central negative filament, thereby neutralizing the space charge and allowing an increased number of electrons to flow to the outer positive cylindrical electrode. In this way a great increase in sensitivity is obtained. They find a sharp maximum at the limit $1s = 3184$A of the principal series, as required by the Bohr theory, but also some effect for longer waves. A possible explanation lies in adding to the energy of the excited atom sufficient energy due to collision with other atoms to effect ionization.

R. C. Burt[118] has investigated the effect of temperature change on the total photoelectric current from sodium, taking great care to avoid errors due to gaseous and other impurities. A novel feature of his work is the method[119] of preparing the metallic surface by electrolytic deposition through the glass to the inside of an incandescent lamp bulb. The total photocurrent was found to be relatively constant for the temperature range $+20°$C to $-190°$C provided the two traps between the cell and diffusion pump were kept immersed in liquid air. If one or both of these were allowed to warm up, however, phenomena occurred such as formerly reported by Ives, which Burt regards as the effect of gaseous impurities.

GENERAL SPECTROSCOPY

Millikan and Bowen[5] have continued their important studies of the spectra of atoms stripped of all except one, two or three of their valence electrons by the hot spark. The spectra of the elements between sodium and chlorine have been examined, the atoms having the effective nuclear charge 1 to 7. The spectra of all atoms with one residual valence electron resembled that of sodium, with frequencies increasing according to Moseley's law. A large number of term values for the series of these elements was determined. The doublet laws of x-ray spectra are found to hold throughout the optical field. This made it possible to predict the exact frequencies which will be emitted by an atom in a given stage of excitation, and the doublet separation to be expected. It was definitely shown that two electrons may simultaneously be subject to orbital displacements, and their joint energy change integrated into a monochromatic wave.

Eddington[120] has pointed out that dwarf white stars of an early type of spectrum may have enormous densities, due to the breaking down of atomic structure caused by complete ionization, while the heterogeneous mixture of nuclei and electrons may behave as a perfect gas. The Einstein shift of spectral lines in the spectrum of such a body would be great because of the relatively great mass and small radius. The companion of Sirius is a dwarf white star of high temperature but of small intrinsic brightness, which indicates small size. From the elements of its orbit its mass and velocity relative to Sirius may be determined, and its absolute magnitude may be determined from the known parallax of Sirius. With a knowledge of its spectral type these data are sufficient to determine its surface brightness, size, and density. If its density is abnormally large, there should be a large Einstein shift in the lines of its spectrum. Adams[121] has made a study of its spectrum which approximately fixes its spectral type and shows the expected Einstein shift. The difficulties were great because Sirius is 10,000 times brighter than its companion, and their images lie near together on the slit of the spectrograph. The images were formed by the 100-inch mirror of Mount Wilson Observatory. The type of spectrum was found to be different from that of Sirius, probably of class F_0, perhaps of earlier rather than of later type, with an extreme alternative of A_5. Many careful measurements of the positions of lines, especially of H_β and H_γ, showed a large displacement toward the red. In the case of H_β this corresponded to a velocity in the line of sight of +26km/s, in the case of H_γ to +21km/s, and the average for all other lines was +22km/s. The average shift was +0.38A. Making corrections for displacements due to Doppler effect, the final conclusions for the alternative spectral types were as follows:

	F_0	A_5
Surface brightness	−0.88	−1.45
Radius	24,000 km	18,000 km
Density (water = 1)	30,000	64,000
(Calculated) Relativity displacement	+0.23Å	+0.32Å.

These figures give a remarkable confirmation of Eddington's calculations, based on a spectral type F_0 and an approximate temperature of 8,000°. They gave a density of 53,000 and a radius of 19,600 km.

A number of observers, notably Vegard, have shown that most of the "lines" in the spectrum of the aurora are the heads of the positive and negative pole bands of nitrogen. The most characteristic line of

the spectrum, however, has not until recently been identified with any known element. It has been shown by Campbell, Slipher, Strutt, and others that it is found in the spectrum of the night sky at all times in different parts of the world. Babcock[122] with an interferometer, found its wave length to be 5577.350 ± .005Å. Vegard believed that he had reproduced this line in the laboratory by bombarding solid nitrogen with cathode rays, but McLennan showed that he was mistaken. McLennan and Shrum[103] (see also earlier mention) have recently found practically the entire auroral spectrum, including the green line, as a part of the spectrum of the discharge in a vacuum tube containing mixtures of helium and air. With a mixture of pure helium and oxygen they observed the helium spectrum, known oxygen lines and the green line. The same was true with mixtures of neon and oxygen, but in no case did they observe the green line when the mixture contained no oxygen. The most favorable proportions were about 1-3 mm partial pressure to oxygen and 2-4 cm of helium. The wave length was found to be 5577.35 ± .15Å. There can be little doubt that this line is identical with that observed in the spectra of the aurora and of the night sky. In other cases it has been found that the presence of helium enhances other spectra or even develops new lines. This may be due to its weak electric field due to its closed electron ring, which likewise determines its chemical inactivity. It may also be due to the fact that the helium atom may be put in a metastable state in which it can transfer its excess energy to other atoms by collisions of the second class. McLennan and Shrum point out the probability that the upper atmosphere contains a large proportion of helium, the product of radioactive changes in the earth. On account of the low pressure, the metastable state due to the absorption of solar radiation may persist during the night. When an excited atom collides with an atom of oxygen or a molecule of nitrogen the excess energy is transferred and light corresponding to the green line of oxygen or the bands of nitrogen is emitted. This goes on throughout the atmosphere, but is of course most energetic in the regions of auroral display. Thus it appears that the green line is an enhanced line of oxygen requiring an energy of 20 volts or more to excite it. It is interesting to note that no helium lines have been found in the auroral spectrum, although they were of course observed by McLennan and Shrum in the laboratory.

VELOCITY OF LIGHT

During the past several summers Michelson[123] has been measuring the velocity of light at Mt. Wilson under more favorable conditions, as

regards accuracy, than have ever obtained before. A beam of light is reflected from a rotating octagonal mirror to a mirror on Mt. San Antonio 22 miles away and on returning strikes the next succeeding face of the rotating mirror and is reflected into the micrometer eyepiece. This is accordingly almost a null method as regards deflection and the emphasis is placed on measuring the speed of rotation of the mirror, which is synchronized with a fork controlled by comparison with a pendulum.

The results—as yet only provisional—including the work of 1924 are given in the last line of the following table:

Investigator	Method	Distance	Weight	Velocity
Cornu	Toothed wheel	23 km	1	299,950
Perrotin	Toothed wheel	12 km	1	299,900
Michelson	Revolving mirror	0.6 km	2	299,895
Newcomb	Revolving mirror	6.5 km	3	299,860
Michelson	Revolving mirror	35.4 km	3	299,820

The results of 1925 are not yet made public but point consistently to a slightly lower value than the accepted one. The eventual aim is to reduce the uncertainty to one part in one hundred thousand.

Relativity then again comes into prominence as a result of two striking experiments, the results of which have been made public during the past year. The first of these is the work of Michelson and Gale[124] in determining the effect of the earth's rotation on the velocity of light. Two beams of light were caused to travel in opposite directions through a rectangle of 12 inch water pipe, of total path length somewhat over a mile, and brought to interference Sharp steady fringes were produced when the air pressure was reduced below an inch of mercury. The beam going counter-clockwise around the rectangle was retarded, giving an observed fringe displacement of $.230 \pm .005$. This agrees with the value ($.236 \pm .002$) computed on the hypothesis of a fixed ether and is also in accord with relativity, so the experiment in this sense is not a critical one. What it does prove is that, if there is an old-fashioned ether, it does *not* rotate with the earth.

Relativity will not fare so well, however, if the results now reported by Miller[12] for his repetition of the Michelson-Morley experiment shall eventually be established beyond question. During the last four years Miller has made thousands of ether-drift measurements both at Mt. Wilson and at Cleveland using every precaution to eliminate mechanical disturbances as well as other possibe souces of error. His conclusion is

that a positive result is shown by all the Cleveland observations and a somewhat larger effect at Mt. Wilson, amounting at the latter place to about 9 km per second, or one-third the orbital motion of the earth, indicating a partial drift of the ether with respect to the earth, which increases with the altitude. (After completing his computations Miller considers that the variation of effect with altitude is within limits of experimental error, and therefore doubtful.) The observations are consistent with a definite absolute motion of the earth through space, combined with the periodic changes due to its orbital motion.

Einstein is quoted as saying that if these results are eventually confirmed, relativity theory, at least in its present form, falls.

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DR. G. A. HERMANN KELLNER

The passing of Dr. Kellner, at his home in Rochester, New York, on January 28, 1926, removes from the Optical Society of America one who, not only because of his widely known scientific work but because of his rare personal qualities, had become one of its outstanding figures. One of its charter members; first editor of its Journal; frequent contributor of papers; always present at its conventions except when prevented by illness, Dr. Kellner did much to place the Society on a solid foundation.

Born July 20, 1873, Dr. Kellner studied at Berlin and Jena, receiving the doctorate from the latter in 1899. After several years in the optical industries of Germany, he came to America and soon became associated with the Bausch and Lomb Optical Company, as Director of its Scientific Bureau. His thorough training in scientific optics, and his unusual gifts as a designer and student of applied optics have left their impress on American optical instruments—notably the microscope, which was always his favorite instrument. Of almost equal importance is his work on modern fire-control instruments. In later years he devoted much time and effort to the development of motion picture projection apparatus. He was a member of the Society of Motion Picture Engineers, and was a prominent figure at its meetings.

Dr. Kellner's interests were not confined to his professional work. He was very fond of both music and art. Watch making was also a

favorite hobby. And he had a very extensive collection of watches and chronometers that date back to the early history of the art.

The members of the Optical Society of America have lost a valued friend and associate; and the optical industry in America has lost one of its best trained and most successful scientists, one whose very success is an eloquent testimonial to the value in modern industry, of a thorough training in basic fundamentals.

F. K. RICHTMYER

Dissociation of hydrogen Molecules by electron-impacts.—The appearance of the Balmer series in the spectrum of a discharge in hydrogen shows that excited H atoms are present; the question is, do these result each directly from a single impact of an electron against a molecule, or otherwise? To prove that some at least arise in the first-named way, Blackett and Franck send a narrow sharply-bounded electron-stream (originating from an oxide-coated spot on a hot band, and accelerated by 30 to 100 volts) through very rarefied hydrogen ($p =$ .007 mm Hg and upwards). If the molecule were first put into an excited state by an electron-impact and then dissociated by a second collision, most molecules would have shot far outside the limits of the electron-stream before dissociating; yet the luminous part of the gas coincided accurately with the region traversed by electrons. If it required two electron-impacts to effect the dissociations, then the two would be separated on the average by 500 or more times the time-interval indicated by Wien's researches as the duration of an excited state. If the free atoms appear spontaneously in the gas, one might expect the intensity of the Balmer lines relatively to the many-lined spectrum to be diminished by increasing the catalytic action of the tube-walls which promotes recombination of free H atoms; this does not happen. These observations make it practically necessary to suppose that impacts of electrons of the aforesaid energy against H_2 molecules sometimes result in dissociation of the molecule with production of at least one excited atom. The continuous spectrum appears to follow the same laws of excitation as the Balmer lines. A most interesting observation is made upon the line-widths. The Hα line of the Balmer series, which is a doublet of sharp lines when emitted by a discharge in gas containing many free atoms, is a hazy doublet or a single broad line when emitted by a discharge in hydrogen in which the tube-walls eliminate the atoms as fast as they appear. This is attributed to the extra Doppler-effect resulting from the speed with which the atoms fly apart from the dissociating molecule; and some quantitative estimates are made. An excellent set of photographs shows the effect.—[P. M. S. Blackett and J. Franck (Göttingen); ZS. f. Phys., *34*, pp. 389–401; 1925.]

KARL K. DARROW

THE RELATION BETWEEN INTENSITY OF FLUORESCENCE AND CONCENTRATION IN SOLID SOLUTIONS

By Ernest Merritt

Solid luminescent materials are usually compounds in which a small amount of some active material is intimately associated with a relatively large amount of an inert substance which acts as a solvent or flux. Such compounds are prepared artificially by evaporating to dryness a mixed solution of the two components, or by mixing the components in powder form and then subjecting the mixture to suitable heat treatment. While we have no means of knowing the form in which the active material exists in these preparations it is generally thought that luminescent materials are to be regarded as solid solutions rather than as chemical compounds.

The variation of brightness with concentration has been studied quantitatively in only a few cases; but it is known that luminescence of considerable intensity may be produced by very minute traces of a suitable active material and that if the concentration is increased beyond a few per cent the brightness is greatly reduced. Maximum brightness is often reached with one part of active material to ten thousand of solvent and the optimum concentration is rarely as great as one part in one hundred.

Broadly speaking the behavior of fluorescent solutions is similar to that of solid luminescent preparations. Fluorescein, for example, which is brilliantly fluorescent in dilute solutions, is almost completely inactive when the solution is concentrated.

The existence of an optimum concentration has been explained by Brüninghaus[1] as the result of absorption. It is assumed that the active material in the surface layers has for some reason lost its ability to radiate, but retains its power of absorbing the fluorescent light that comes from the interior of the mass. Increase in concentration causes an increase in the fluorescence excited in the interior, presumably in proportion to the number of molecules of the active material; but it also brings about increased absorption of this fluorescent light by the

[1] Brüninghaus, L., Comptes Rendus de l'Acad. des Sciences., *149*, p. 1375; 1909.

surface layer. The intensity of the light that escapes and is observed is therefore given by an equation of the form

$$I = Kxe^{-kz} \tag{1}$$

where x is the concentration of the active material.

Brüninghaus finds that this equation represents with considerable exactness measurements made on the cathodo-luminescence of manganese in calcium phosphate.

Doubt is thrown on the correctness of the Brüninghaus theory by the fact that the hypothesis on which it is based, which is certainly not true in the case of fluorescent liquids, has received no experimental verification in the case of solids. The equation developed by Brüninghaus fails also to represent the results of the more recent experimental work.

Perrin[2] has suggested two alternative reasons for the decrease in luminescence at higher concentrations:

(1) The exciting light is in the form of quanta of small cross section, and if two active molecules are so close together that they are struck by the same quant, the energy is divided between the two and is less likely to cause excitation; or (2) when two active molecules are sufficiently close together, their fields overlap and they are coupled in such a way as to diminish their power of responding to excitation.

If the first explanation suggested by Perrin is correct we should expect the optimum concentration to depend primarily upon the cross-section of the light quant. It would appear likely, therefore, that the optimum concentration would depend upon the wave length of the exciting light or upon the nature of the solvent. No experimental evidence on these points is available. Several observers have pointed out, however, that the optimum is reached at smaller concentration when light is the exciting agent than when the substance is excited by cathode rays. If we accept Perrin's first suggestion it seems clear therefore that the cross-section of a light quant must be greater than the effective cross-section of the electrons in the cathode ray. It appears to me not unlikely that a satisfactory theory based upon the assumption of light quanta of definite cross-section could be developed. Yet the difficulties and uncertainties are considerable, and it seems preferable to attempt first to make Perrin's second suggestion the basis of a quantitative theory.

[2] Perrin, J., Ann. de Phys., *11*, p. 5; 1919.

In the case of liquids the relation between fluorescence and concentration has been investigated by F. Perrin[3] and by Wawilow,[4] each of whom based his theoretical discussion upon the general assumption that fluorescing power is destroyed when two active molecules are close together. For a thin layer of the liquid and large values of the concentration both Perrin and Wawilow find that the intensity of fluorescence is given by an expression of the same form as that proposed by Brüninghaus for solids, and this conclusion is confirmed by the experimental results. But for small concentrations there is complete lack of agreement, both as to the form of the theoretical expression for the fluorescence and as to the results of experiment. Both Perrin and Wawilow assume that diffusion of the active material during the period between excitation and reemission is an important factor; in Wawilow's discussion it is the essential factor. In a solid it would seem that the displacement resulting from diffusion, in the extremely short time during which the molecule remains in the excited state, would be so small as to be negligible. In the discussion that follows I have assumed that this is true.

If the optimum concentration is as small as one molecule of active material to 1000 molecules of solvent—and maximum brightness has frequently been found for still smaller concentrations—we must conclude that on the average each active molecule is separated from its nearest neighbor by about ten molecules of the solvent. It is hard to believe that under such circumstances the two molecules could influence one another to such an extent as to interfere seriously with their excitation. But if the active molecules are distributed at random there will be some whose distance apart is much less than the average distance. And it is clear that the number of molecules that are separated by a given small distance from their nearest neighbor will increase both absolutely and relatively as the concentration is increased.

To put the Perrin suggestion into quantitative form let us assume therefore that if two active molecules are at a distance apart that is less than some distance ρ their luminescence is either completely destroyed or greatly reduced. If we direct our attention to some one molecule A, the probability that another molecule B will *not* lie within the sphere of radius ρ is $(V-v)/V$,where V is the total volume and v the the volume of the sphere of radius ρ. The probability that all of the

[3] Perrin, F., Comptes Rendus de l'Acad. des Sciences, *178*, p. 1978; 1924.
[4] Wawilow, S. J., Zsch. für Physik, *31*, p. 750; 1925.

other molecules will lie outside v is $(1-v/V)^n$ where n is the total number of active molecules. The number of active molecules that are so far apart as to be free to radiate is therefore $n(1-v/V)^n$. If subjected to some exciting agency each of these undisturbed molecules will radiate and, neglecting absorption, the intensity of luminescence will be

$$I = Fn(1-v/V)^n$$

It is convenient to take $V = 1$ cc and $n =$ the number of active molecules per cc. If this change is made

$$I = Fn(1-v)^n = Fne^{-rn} \tag{2}$$

where

$$r = -\log_e (1-v)$$

With a suitable change in r and F the concentration may be expressed in any convenient form.

It will be noticed that this expression for I has the same form as that proposed by Brüninghaus.

The expression requires modification, however, because of absorption. The exciting light suffers absorption, so that excitation is less intense at points in the interior than at the surface; and the emitted light is in part absorbed on its way out. In each case the absorption is partly due to the solvent and partly to the active material. The latter part of the absorption may be assumed to increase in proportion to the concentration. We must therefore make use of two absorption coefficients, $a+bn$ for the exciting light and $p+qn$ for the emitted light.

In a layer of thickness dy and unit area at a depth y below the surface there are $n(1-v)^n dy$ active molecules free to radiate and these are subjected to exciting light of intensity $I_0 e^{-(a+bn)y}$. If the fluorescence is proportional to the intensity of the exciting light—and such proportionality is confirmed by experiment in all cases where tests have been made—the light emitted by the layer dy is $Fn(1-v)^n e^{-(a+bn)y} dy$, of which the fraction $e^{-(p+qn)y}$ reaches the surface.

The intensity of the light issuing from the surface is therefore

$$I = \int_0^\infty FI_0 n(1-v)^n e^{-(a+bn)y} e^{-(p+qn)y} dy$$

$$= FI_0 \frac{n}{\alpha+\beta n}(1-v)^n = F\frac{n}{\alpha+\beta n}e^{-rn} \tag{3}$$

where

$$\alpha = a+p \qquad \beta = b+q \qquad r = -\log(1-v)$$

It is assumed that the specimen is so thick that the exciting light is completely absorbed.

Since the concentration is usually given as the ratio of n to N, where N is the number of solvent molecules per cc, and since the form of the curve depends only on the ratio of α to β, it is convenient to write the equation in the form

$$I = K\frac{x}{c+x}e^{-kx} \tag{4}$$

where

$$x = n/N \qquad k = rN = -N\log(1-v)\,, \qquad c = \alpha/\beta$$

Equation (4) may be shown to be consistent with all of the peculiarities in the relation between I and n to which different observers have called attention. For example:

1. It has been pointed out by Urbain[5] that when the luminescence spectrum consists of several bands the optimum concentration is in general different for each. Since the bands occur in different parts of the spectrum, and since in general each band has its own region of excitation, the absorbing power of the mass, both for the exciting light and for the emitted light, will vary from band to band. In consequence the constant c will have different values and the concentration for maximum I will change.

2. If k is small the exponential term in equation (4) will remain nearly equal to unity until relatively large values of x are reached and for small concentrations the form of the curve will depend chiefly on the value of c. For c small the intensity will therefore rise rapidly to a large value and will then remain nearly independent of x until the exponential factor becomes of importance. Several cases of this kind are on record.

3. Kowalsky and Garnier[6] have found that for a given substance the optimum concentration is smaller for light excitation than for excitation by cathode rays. Samarium in CaS, for example, gave maximum brightness with ultraviolet excitation when the concentration was one molecule of samarium to 3000 molecules of Ca. The same phosphors with cathode ray excitation showed maximum brightness for the preparations containing one molecule of samarium to 400 of calcium. This is doubtless the result of the fact that the cathode

[5] Urbain, G., Comptes Rendus de l'Acad. des Sciences, *147*, p. 1472; 1908.

[6] Kowalsky, J., and Garnier, G., Comptes Rendus de l'Acad. des. Sciences, *145*, p. 391; 1907.

rays penetrate only a short distance and that their absorption is due almost entirely to collisions with the solvent molecules. For cathodo-luminescence the constant c is therefore large. On the other hand the solvent is relatively transparent to light. For photo-luminescence c is therefore likely to be small and I reaches its maximum for small values of x. It will be noticed that when c is large equation (4) becomes practically identical with the expression proposed by Brüninghaus.

An excellent opportunity for a quantitative test of equation (4) is afforded by the work of Nichols and Slattery[7] who have recently determined the intensity of fluorescence as a function of concentration in

TABLE 1

Phosphor	K	c	k	s
Uranyl fluorid in sodium fluorid	170	.000005	1.30	3.1
Uranyl fluorid in calcium fluorid	202	.00025	.91	2.8
Uranyl phosphate in sodium phosphate	165	.0008	.25	1.8

the case of three different uranium phosphors. In each of the three cases I have determined K, c and k by trial and have then plotted the

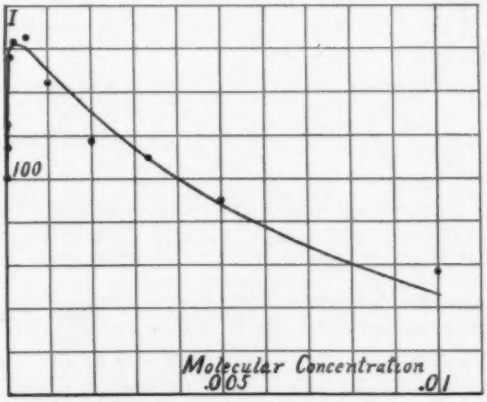

FIG. 1. *Uranyl fluorid in sodium fluorid.*

observed and computed values of I against x. The results are shown in Figs. 1, 2 and 3. In each case the curve is plotted from equation (4) while the experimental data are indicated by black circles. The constants K, c and k for each of the three phosphors are given in Table 1.

[7] Nichols, E. E. and Slattery, M., J.O.S.A. & R.S.I., *12*, p. 449, 1926.

In the case of uranyl fluorid in sodium fluorid (Fig. 1) the optimum concentration, about .0002, is smaller than for either of the other phosphors studied. For concentrations lying between .00001 and .01 the agreement between the observed and computed values of I is as close as could be expected, since the location of the observed points indicates that the experimental errors are of the order of 5 per cent. For concentrations less than 10^{-5} the agreement is less satisfactory. Thus for $n = 10^{-6}$ the observed value of I is 100, while the computed value is 29. For $n = 10^{-7}$ the two values are 39 and 4 respectively.

In the curve for uranyl fluorid in calcium fluorid (Fig. 2) the computed and observed values of I do not in any case differ by more than

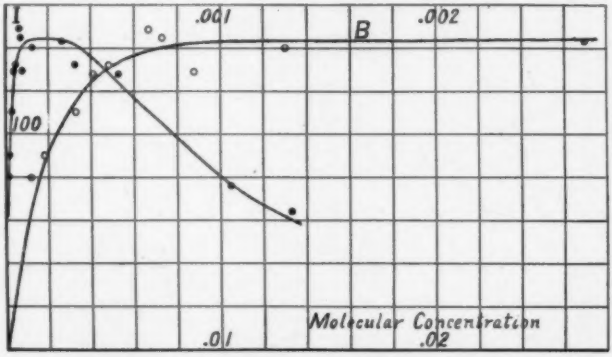

FIG. 2. *Uranyl fluorid in calcium fluorid. For Curve B the horizontal scale is indicated at the top.*

the experimental errors. In the case of this phosphor the concentration was varied from .00012 to .0133. In curve B the data for small concentrations have been plotted to a larger scale in order to show the form of the curve in this region more clearly.

Fig. 3 shows the computed curve and the observational data in the case of uranyl phosphate in sodium phosphate. Here also the data for small concentrations have been replotted in Curve B to a larger scale.

In view of the great difficulty of preparing a suitable series of phosphors, which arises both from the difficulty of obtaining pure materials and from the fact that the heat treatment must be identical for the different mixtures, the agreement between the computed and observed curves seems in all three cases as satisfactory as could be expected.

The phosphors investigated by Nichols and Slattery are unusual in the fact that the active material is one which is luminescent when pure.

In some cases the uranyl salt shows fluorescence when pure that is nearly as bright as is that of the solution at optimum concentration. It would appear that when two molecules of uranium are brought close together their power to fluoresce is not completely destroyed but only reduced. When the molecules are all crowded together, as in the pure

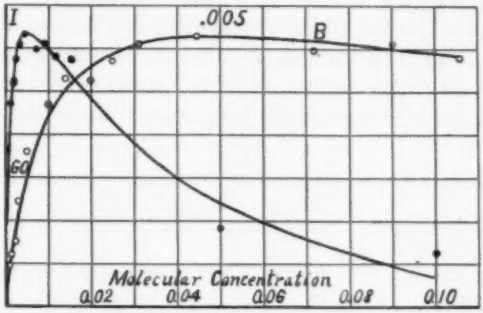

FIG. 3. *Uranyl Phosphate in sodium phosphate. For Curve B the horizontal scale is indicated at the top.*

substance, the diminished activity of the individual molecules is offset by the greatly increased number present. If equation (4) is modified to correspond to the assumption of reduced activity, rather than complete destruction of luminescence, when the distance between molecules is less than ρ, the equation takes the form

$$I = K_1 \frac{x}{c+x} e^{-kx} + K_2 \frac{x}{c_1+x}$$

In the second term a new constant c_1 takes the place of the constant c of the first term, since it is not to be expected that either the color of the emitted light or the exciting region will be the same when the active molecules are close together. The fluorescence of the uranyl salts in bulk is in fact quite different in color from that of the phosphors studied by Nichols and Slattery. Indeed we are hardly justified in putting I equal to the sum of two terms, for the tacit assumption has been that both the emitted and exciting light are monochromatic; the application of equation (4) to a phosphor having a broad band can only be justified as a reasonably close approximation. Without developing a more complicated equation—and the lack of experimental data for testing such an equation makes this step unprofitable at the present time,—we can therefore only say that for large concentrations of the uranium salts somewhat brighter fluorescence is to be expected than that com-

puted from equation (4). Inspection of Figs. 1, 2 and 3 shows that the experimental results are in agreement with this conclusion.

In the case of the phosphate (Fig. 3) where the concentration was carried to 0.1 it is to be expected that the difference between the observed and calculated values of I for large values of x will be expecially large; and the difference is in fact greater in this case than in either of the other phosphors tested. It is possible that a better value of k would have been obtained by ignoring the observed point at $x=0.1$.

The value of ρ may be computed from the experimentally determined value of k. Since, however, the concentration x has been expressed as the ratio of the number of molecules of the active material to the number of molecules of the solvent, and since also the density of the mass is not known, it will be convenient to express ρ in terms of the average distance between the molecules of the solvent. Assuming a simple cubic lattice, with N molecules of solvent and n of the active material per cubic centimeter, the minimum distance apart of the solvent molecules is $d=N^{-1/3}$ cm. Let $\rho=sd$. Then

$$v=\frac{4}{3}\pi\rho^3=\frac{4}{3}\pi s^3N^{-1}$$

Since v is small we may write

$$k=-N\log(1-v)=Nv=\frac{4}{3}\pi s^3$$

$$s=(3k/4\pi)^{1/3}$$

The values found for s from this equation are given in the last column of Table 1. The phosphors are arranged in the order of the molecular weights of the solvent. It will be noticed that c increases as we pass to solvents of higher molecular weight, and that s diminishes.

In Table I the largest value of s, that for uranyl fluorid, is 3.1. We must conclude, therefore, that when two molecules of uranium are separated from one another by only two molecules of solvent, or are still closer together, they act upon one another in such a way as to reduce greatly their power to fluoresce. That some action of this sort should occur at so small a distance is not improbable. But another interpretation of the results is possible, namely, that if, in the process of mixing the materials of the phosphor, two active molecules are brought within the distance ρ of one another, opportunity is offered by the subsequent heat treatment for them to come still closer, so that a poly-

merized molecule may be formed, or possibly some chemical combination in which two molecules attach themselves to a single solvent molecule. If this interpretation is correct we should expect that prolonged heat treatment would lead to larger values of ρ and k.

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Depolarization of resonance Radiation by alternating magnetic Field—Suppose that resonance radiation is produced in the classical manner; i.e. that a light-beam with its electric vector parallel to the z axis causes oscillations of a free (or isotropically bound) electron. If a magnetic field is applied along the y axis, the line of vibration of the electron will rotate around the y axis with the frequency of the Larmor procession; if this is great compared with the frequency of the light, the radiation emitted by the electron along the y direction will appear unpolarized; if however the field is alternating instead of constant, the direction of rotation will be reversed in every half-period of the field, and the higher the frequency of alternation of the field the more nearly will perfect polarization of the light be restored. Experiments with fields alternating at frequencies of 1.2 to 5 millions, and λ2536, showed that when the amplitude of the field is 1.14 gauss, the polarization increases with the frequency; when the amplitude is 1.66 gauss it increases with frequency perceptibly from 3.10^6 onward; with the amplitude 2.13 gauss it remains sensibly constant. The theory, which is not reproduced, apparently involves an assumption that the damping of the oscillating electron is related in some way to the observed "life," 10^{-7} second, of the mercury atom in the excited state. The authors think that the accuracy of their data is sufficient to show, by comparison with their theory, that the precession occurs at 3/2 the Larmor rate.—[E. Fermi and F. Rasetti, University of Florence; ZS., f. Phys., *33*, pp. 246-50; 1925.]

KARL K. DARROW

Attempt to determine the ionizing-potential of phosphorus.—The method consisted in determining striking and breaking potentials of a low-voltage arc in a two-electrode tube containing P vapor; these potentials varied rapidly with vapor-pressure, having minimum values both near 10.3 volts when the tube was maintained near 333°C. Further experiments at this vapor pressure with the anode in the form of a box enclosing the cathode (so that it might grow very hot and the vapor within be highly dissociated) yielded current-voltage curves bending sharply upward near 10.3 volts. (These numerical values appear to involve large and uncertain corrections to actual voltage readings). The value 10.3 is therefore proposed for the ionizing-potential of P atoms.—[O. S. Duffendack and H. Huthsteiner (Gen. El. Co.); Phys. Rev., (2), *25*, pp. 501–08; 1925.]

KARL K. DARROW

INSTRUMENT SECTION

A NEW RELATIVE HUMIDITY RECORDER

By Leo Behr

ABSTRACT

Recorder Mechanism.—A mechanism is described capable of automatically balancing any network of impedances where the balance point is attained by the motion of one or more sliders along slide wires, and where the balance point is determined by the absence of current in the recorder galvanometer.

Relative Humidity Curves.—From the formula for relative humidity in terms of the wet and dry bulb temperatures, it is shown that for constant humidity the relation between wet and dry bulb temperatures is very nearly a linear one, and that the value of the humidity is uniquely defined by the ratio (wet bulb temp.—A)/(dry bulb temp.—B) where B is a constant and A is a function of the relative humidity but changes only slightly with it.

Recorder Circuit.—By using a nickel resistance thermometer in a network which is essentially a split circuit potentiometer, it is possible to secure a potential difference across the ends of a slide wire which is directly proportional to (dry bulb temp.—B). In another very similar circuit a potential difference is gotten which is proportional to (wet bulb temp–A). This latter potential difference is automatically balanced against a portion of the former by the recorder mechanism mentioned above, and the position of balance is indicative of the ratio (wet bulb temp.—A)/(dry bulb temp.—B) so that the instrument reads directly in relative humidity.

The results of a check on the finished instrument are given from which it appears that the approximations made in the design and any inaccuracies introduced in the actual construction are of no greater magnitude than the uncertainties in the humidity formula itself.

Maintenance of Wet Bulb.—Two forms of wet bulb are described which are capable of continuous operation. In one the customary wick is replaced by a spray, and in the other a long wick is provided so that a clean portion can be substituted for the soiled part merely by turning a roller to wind the wick from one holder on to another.

The problem of continuously recording relative humidity has been solved in various ways but, as far as the writer is aware, no thoroughly satisfactory method has been worked out. Such devices as have appeared have, in general, been inaccurate and unreliable, or else undesirably complicated.

The interesting solution described by Mr. E. B. Wheeler, in the Bell System Technical Journal (April, 1924), appears to be eminently satisfactory so far as accuracy is concerned but the electrical circuits are more complicated than one would wish. There is also the chance of error from contact resistance variation in various bridge arms unless such contacts are occasionally watched.

It was suggested by Mr. Wood of the Bell Telephone Laboratories that a simpler method would be desirable. An effort to simplify the method, while retaining the obvious merits of the design described by Mr. Wheeler, has led to a construction which is at once simple and reliable as well as remarkably accurate.

As a preface to a description of the humidity recorder it is desirable to outline briefly the operation of the recorder mechanism itself, as without such description, later references may not be clear.

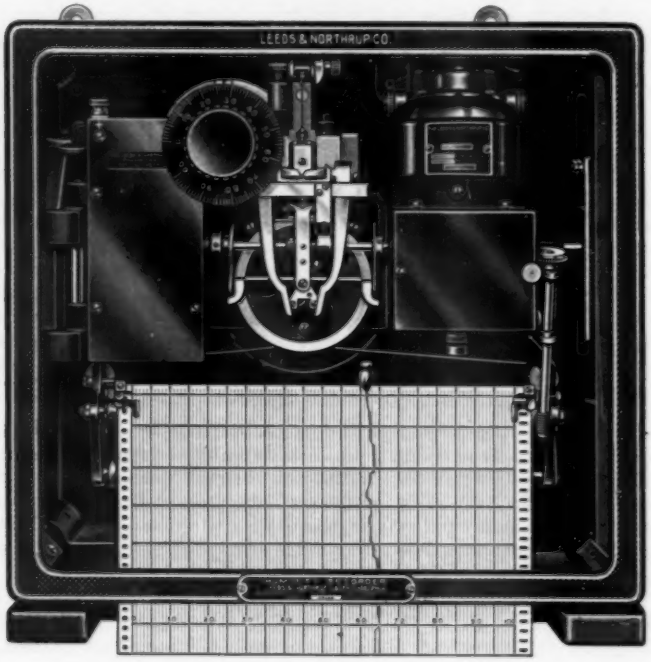

FIG. 1

RECORDER MECHANISM

Fig. 1 depicts a front view of the type of recorder employed and Fig. 2 a view of the rear working parts. The recorder may be employed as a self-balancing Wheatstone bridge or potentiometer, or may be used to balance any network of impedances where the balance point is attained by the motion of one or more sliders along slide wires, and where the balance point is determined by the absence of current in the recorder galvanometer.

The humidity recorder to be described is based upon the principle of the potentiometer but to assist in an understanding of the recorder mechanism itself, a simple Wheatstone bridge circuit is shown con-

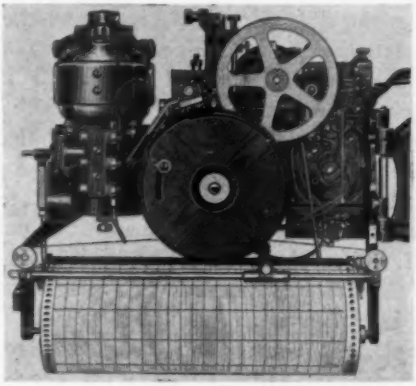

FIG. 2

ventionally in Fig. 3. The Wheatstone bridge comprises four resistance arms, namely: the arm from M to the point F where the sliding contact engages the slide wire S, the arm from N to F, the arm of resistance

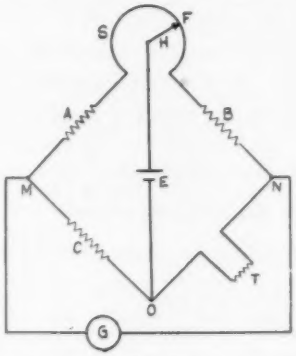

FIG. 3

C from M to O, and the arm from N to O consisting of a resistance thermometer T. The battery E connects the conjugate points O and F and the galvanometer G connects the conjugate points M and N.

If now the thermometer T is at such a temperature that its resistance equals that of the coil C, then, since the resistances A and B are equal,

the slider H will have to be placed midway of the length of the slide wire S in order to balance the bridge and reduce the galvanometer current to zero.

There will be noticed a disc on the back of the recorder in Fig. 2. This disc carries the slide wire S of Fig. 3 and the function of the recorder is to rotate the disc and slide wire until the bridge is balanced. The slide wire S is rotated instead of the slider F but this does not change the principle of operation.

Referring again to Fig. 2, it should be noted that a small cable, wrapped around the slide wire disc, is attached to a pen carriage and moves the pen along the chart whenever the disc rotates. Each position of the pen, consequently, corresponds to a definite position of the disc and slide wire S. When, therefore, the bridge is balanced each position of the pen on the chart corresponds to a definite resistance of the thermometer T and, therefore, of the temperature of the thermometer.

If, for example, the temperature of the thermometer increases, thereby increasing the resistance of the arm ON, the disc will be rotated by the recorder motor so as to change the position of the contact F with respect to the slide wire S, in this instance shifting the point F toward A. When the galvanometer comes to a balance the disc stops and the pen indicates, by its position on the chart, the actual temperature of the thermometer T.

RELATIVE HUMIDITY CURVES

The formula for relative humidity, as given in terms of the wet and dry bulb temperatures by Landolt-Börnstein, is taken as correctly representing the facts. In the notation to be used this becomes

$$\text{Relative Humidity} = \frac{p_t - \frac{1}{2}(\theta - t)\frac{b}{755}}{p_\theta} = \frac{p_a}{p_\theta}$$

where

θ = dry bulb temperature in degrees C.

t = wet bulb temperature in degrees C.

p_θ = pressure, in millimeters of mercury, of saturated water vapor at temperature θ.

p_t = pressure, in millimeters of mercury, of saturated water vapor at temperature t.

b = barometric pressure in millimeters of mercury.

p_a = actual pressure, in millimeters of mercury, of water vapor at temperature θ.

TABLE 1.

h	θ	t	t_{SL}	$t-t_{SL}$
.80	40	36.57	36.55	+.02
.80	30	27.10	27.13	−.03
.80	20	17.70	17.71	−.01
.80	10	8.30	8.29	+.01
.60	40	32.60	32.54	+.06
.60	30	23.85	23.85	±.00
.60	20	15.17	15.17	±.00
.60	10	6.52	6.49	+.03
.40	40	27.90	27.89	+.01
.40	30	20.11	20.14	−.03
.40	20	12.41	12.38	+.03
.40	10	4.61	4.62	−.01
.30	40	25.18	25.21	−.03
.30	30	18.05	18.04	+.01
.30	20	10.93	10.86	+.05
.30	10	3.63	3.68	−.05
.20	40	22.14	22.23	−.09
.20	30	15.80	15.73	+.07
.20	20	9.36	9.23	+.13
.20	10	2.62	2.73	−.11

h = relative humidity
θ = dry bulb temperature in degrees C
t = wet bulb temperature in degrees C
t_{SL} = wet bulb temperature as computed from straight line approximation.

For $h=80$ $t_{SL}=.94210\ \theta-1.135$
$h=60$ $t_{SL}=.86832\ \theta-2.195$
$h=40$ $t_{SL}=.77570\ \theta-3.135$
$h=30$ $t_{SL}=.71770\ \theta-3.495$
$h=20$ $t_{SL}=.65000\ \theta-3.770$

Variations in the barometric pressure produce slight and in general negligible changes in the computed values of the humidity. Differentiating the formula for the humidity with respect to the barometric pressure:

$$\frac{\delta h}{\delta b} = -\frac{\theta - t}{2\times 755\times p_\theta}$$

An idea of the order of magnitude of the effect is obtained by substituting the approximate values for θ, t and p for several values of the humidity at ordinary temperatures.

For 100 per cent the effect is zero.

For $h=.80 \quad \theta=20°C \quad \theta-t=2.3 \quad p_\theta=17.55.$

$$\frac{\delta h}{\delta b}=\frac{2.3}{2\times 755\times 17.55}=.009\% \text{ per mm}$$

For $h=.20 \quad \theta=20°C.$

$$\frac{\delta h}{\delta b}=.04\% \text{ per mm}$$

Taking b as 755, Table 1 was computed from the formula above and gives corresponding values of θ and t for several humidities. By the method of least squares, the equations were then determined of the straight lines which best represent the relation between θ and t for the

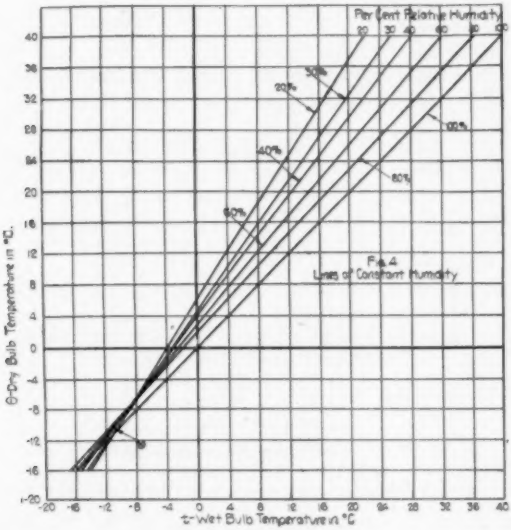

FIG. 4

various humidities. Substituting back in these equations the values 40, 30, 20, and 10 for θ, the values of t were obtained which are tabulated in the column headed t_{SL}.

The column $(t-t_{SL})$, therefore, represents the difference between the correct value of the wet bulb temperature (t) and the value (t_{SL}) got by assuming a straight line relation between wet and dry bulb temperatures. Throughout the entire range, the average deviation from

a straight line is .04°C, and the maximum deviation .13°C. In the range of humidities from .30 to 1.00 these figures become .03° and .06°C, respectively.

Fig. 4 is a plot of Table 1 and shows graphically the relation between θ and t, on the assumption of a straight line relation. If these straight lines are extended to the left, beyond the range in which they are actually used, they all intersect each other in points which do not lie very far apart.

The extrapolation of these straight lines below 0°C is shown to an enlarged scale in Fig. 5. It is quite immaterial for our present purpose whether or not the extrapolated curves correctly represent the state of

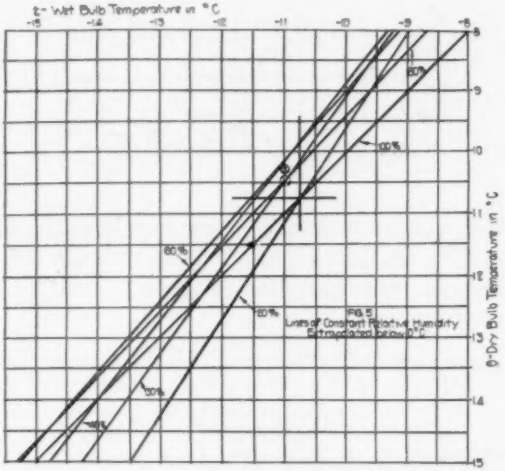

FIG. 5

affairs in the region below 0°C, the essential point being that they are an extension of lines which do represent the facts in the region to be used. The point in Fig. 5 through which all the straight lines most nearly pass is indicated by ⊗ but it is to be noted that the assumption of a single point of intersection may introduce an error whose maximum value is .3°C.

For the sake of completeness it is desirable to insert here Fig. 6 although the purpose will not be apparent until later. An inspection of Fig. 5 indicates that the vertical and horizontal dimensions of the band enclosing the set of straight lines is a minimum at the place where the .20 and 1.00 intersect ($t = -10.77$, $\theta = -10.77$) and is

indicated in the figure by the intersection of the short vertical and horizontal lines. Fig. 6 is a plot of the values of t at points of inter-

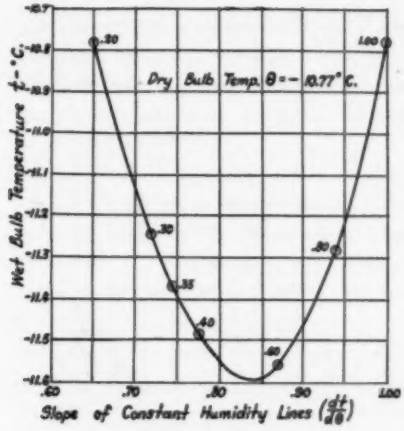

FIG. 6

section of this horizontal line with the constant humidity lines, against the reciprocals of the slopes $(dt/d\theta)$ of the corresponding constant humidity lines. The values are listed in Table 2.

TABLE 2.

h	θ	t	$dt/d\theta$	$d\theta/dt$
1.00	−10.77	−10.77	1.00000	1.00000
.80	−10.77	−11.28	.94210	1.06146
.60	−10.77	−11.55	.86832	1.15165
.40	−10.77	−11.49	.77570	1.28916
.30	−10.77	−11.22	.71770	1.39334
.20	−10.77	−10.77	.65000	1.53846

h = relative humidity
θ = dry bulb temperature in degrees C.
t = corresponding wet bulb temperature
$\frac{d\theta}{dt}$ = slope of the straight lines in Fig. 4
$\frac{dt}{d\theta}$ = reciprocal of the slope

All the computations were carried out on a calculating machine, so it was easier to carry more figures in the numerical work than the

accuracy of the assumptions would justify rather than to go through the trouble of determining the number of significant figures to be retained in each step of the computations.

Assuming for the moment that the constant humidity lines all intersect in one point (t_A, θ_A) as in Fig. 7, it is clear that the humidity for wet bulb temperature t_Q and dry bulb temperature θ_Q is uniquely

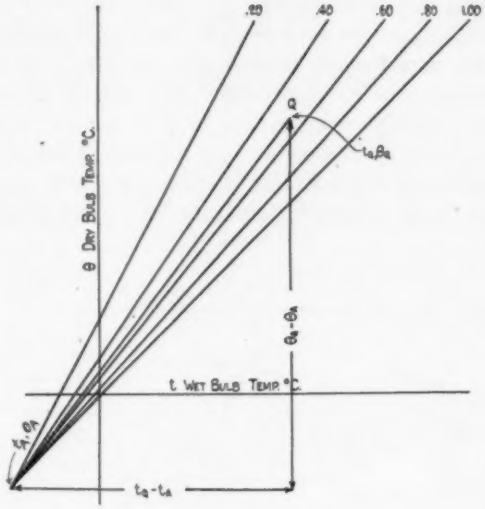

FIG. 7

defined by the reciprocal of the slope of the line connecting the points (t_A, θ_A) and (t_Q, θ_Q) and moreover this reciprocal is given by the expression:

$$\frac{t_Q - t_A}{\theta_Q - \theta_A}$$

Outlining what it is contemplated doing, the total potential difference across a slide wire is to be made proportional to $(\theta - \theta_A)$ and another potential difference is to be secured which is proportional to $(t - t_A)$. $\frac{t_Q - t_A}{\theta_Q - \theta_A}$ is never greater than unity. Balancing the latter potential difference against a portion of the former, as in a potentiometer, the position of balance attained on a slide wire is indicative of the desired ratio. The circuits necessary to accomplish this result will now be described.

DRY BULB CIRCUIT

Referring to Fig. 8, $R_0(1+\alpha X+\beta X^2)$ is the resistance of a dry bulb thermometer at temperature X°C. $(\delta-1)R_0$ and γR_0 are the resistances of two fixed coils, ρR_0 and ρR_0 are the resistances of two equal fixed coils and μR_0 is the resistance of a slide wire. It may be noted that this slide wire is the one depicted in Fig. 2 as being mounted on the recorder disc and rotated by the recorder motor until a balance is attained.

The potential across the network is E and the currents in the various branches of the circuit are indicated by i, j, and k. It is possible to so proportion the various resistances that the current through μR_0 and, therefore, the potential drop from A to B is directly proportional to the departure of the thermometer from some fixed temperature. This in itself, however, is not sufficient because the potential of neither A nor B is fixed, and as will be apparent later, this would prevent a

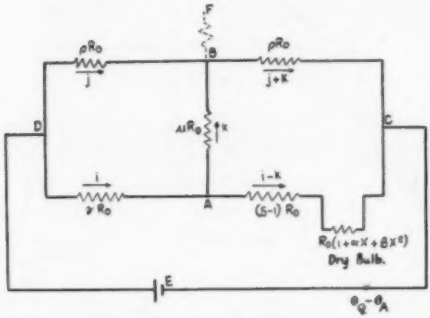

FIG. 8

balance of the complete circuit by a simple automatic adjustment of but a single point. If, however, we imagine, as indicated by the dotted line in Fig. 8, that a resistance of value $\rho/2R_0$ is connected to B, and that some external battery maintains a current through this resistance of the same value as that through μR_0, then the far end, F, remains at a fixed potential which is the mean of that at C and at D.

We can, therefore, think of the slide wire as extending from F to A with only the portion from B to A available for balancing. This range, however, proves ample. The detailed theory relating to this portion of the humidity recorder circuit follows.

CALCULATIONS FOR DRY BULB CIRCUIT

Referring to Fig. 8 and calling the total potential across the circuit E.

$$\rho(2j+k)=\frac{E}{R_0}$$

$$\gamma i+(i-k)(\delta+\alpha X+\beta X^2)=\frac{E}{R_0}$$

$$\gamma i+\mu k-\rho j=0 \qquad (1)$$

from which

$$\rho j=\frac{E}{2R_0}-\frac{k\rho}{2}$$

$$\gamma i+\mu k=\frac{E}{2R_0}-\frac{k\rho}{2}$$

$$\gamma i=\frac{E}{2R_0}-\frac{k\rho}{2}-\mu k$$

$$i=\frac{E}{2R_0\gamma}-\frac{k\rho}{2\gamma}-\frac{\mu k}{\gamma}$$

$$\frac{E}{2R_0}-\frac{k\rho}{2}-\mu k-k(\delta+\alpha X+\beta X^2)+\left(\frac{E}{2R_0\gamma}-\frac{k\rho}{2\gamma}-\frac{\mu k}{\gamma}\right)(\delta+\alpha X+\beta X^2)=\frac{E}{R_0}$$

$$-k\left(\frac{\rho}{2}+\mu\right)-k(\delta+\alpha X+\beta X^2)+\frac{E}{2R_0\gamma}(\delta+\alpha X+\beta X^2)-\left(\frac{k\rho}{2\gamma}+\frac{\mu k}{\gamma}\right)(\delta+\alpha X+\beta X^2)=\frac{E}{2R_0}$$

$$k\left\{\left(\frac{\rho}{2\gamma}+\frac{\mu}{\gamma}\right)(\delta\times\alpha X+\beta X^2)+\left(\frac{\rho}{2}+\mu+\delta+\alpha X+\beta X^2\right)\right\}=\frac{E}{2R_0}\left(-1+\frac{\delta+\alpha X+\beta X^2}{\gamma}\right)$$

$$k=\frac{E}{2R_0}\ \frac{\delta-\gamma+\alpha X+\beta X^2}{\left(\frac{\rho}{2}+\mu\right)(\delta+\alpha X+\beta X^2)+\gamma\left(\frac{\rho}{2}+\mu+\delta+\alpha X+\beta X^2\right)}$$

$$=\frac{E}{R_0}\ \frac{\delta-\gamma+\alpha X+\beta X^2}{(\rho+2\mu)(\delta+\alpha X+\beta X^2)+\gamma\rho+2\gamma\mu+2\gamma(\delta+\alpha X+\beta X^2)}$$

$$k=\frac{E}{R_0}\ \frac{\delta-\gamma+\alpha X+\beta X^2}{(2\mu+\rho+2\gamma)(\delta+\alpha X+\beta X^2)+(2\mu+\rho)\gamma} \qquad (2)$$

The development of k in a Taylor's Series in the neighborhood of $X = X_p$ is of the form:

$$k = k_p + \frac{dk}{dX_p}(X - X_p) + \frac{1}{2}\frac{d^2k}{dX_p^2}(X - X_p)^2 + \cdots$$

where by k_p, dk/dX_p and d^2k/dX_p^2 are meant the values assumed by k, dk/dX and d^2k/dX^2 when $X = X_p$.

From

$$k = \frac{E}{R_0}\,\frac{\delta - \gamma + \alpha X + \beta X^2}{(2\mu+\rho+2\gamma)(\delta+\alpha X+\beta X^2)+(2\mu+\rho)\gamma} \tag{2}$$

$$\frac{dk}{dX} = \frac{E}{R_0}\,\frac{D(\alpha+2\beta X) - (\delta-\gamma+\alpha X+\beta X^2)(2\mu+\rho+2\gamma)(\alpha+2\beta X)}{D^2} \tag{3}$$

When D is put for the denominator of the fraction in equation (2)

$$\begin{aligned}\frac{dk}{dX} &= \frac{E}{R_0}(\alpha+2\beta X)\frac{D-(\delta-\gamma+\alpha X+\beta X^2)(2\mu+\rho+2\gamma)}{D^2} \\ &= \frac{E}{R_0}(\alpha+2\beta X)\frac{D+\gamma(2\mu+\rho+2\gamma)-(\delta+\alpha X+\beta X^2)(2\mu+\rho+2\gamma)}{D^2} \\ &= \frac{E}{R_0}(\alpha+2\beta X)\frac{(2\mu+\rho)\gamma+(2\mu+\rho+2\gamma)\gamma}{D^2} \\ &= \frac{E}{R_0}\,\frac{\{(2\mu+\rho)\gamma+(2\mu+\rho+2\gamma)\gamma\}\{\alpha+2\beta X\}}{\{(2\mu+\rho+2\gamma)(\delta+\alpha X+\beta X^2)+(2\mu+\rho)\gamma\}^2}\end{aligned} \tag{4}$$

When $X = X_p$ and substituting from

$$\begin{aligned}\boldsymbol{\alpha} &= \alpha + 2\beta X_p \\ \boldsymbol{\delta} &= \delta + \alpha X_p + \beta X_p^2\end{aligned}$$

$$\begin{aligned}\frac{dk}{dX_p} &= \frac{E}{R_0}\,\frac{\{(2\mu+\rho)\gamma+(2\mu+\rho+2\gamma)\gamma\}\boldsymbol{\alpha}}{\{(2\mu+\rho+2\gamma)\boldsymbol{\delta}+(2\mu+\rho)\gamma\}^2} \\ &= \frac{E}{R_0}\,\frac{\{(2\mu+\rho)\gamma+(2\mu+\rho+2\gamma)\gamma\}\boldsymbol{\alpha}}{\left\{\left(\boldsymbol{\delta}+\dfrac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}\right)(2\mu+\rho+2\gamma)\right\}^2}\end{aligned} \tag{5}$$

By putting K for the constant factor in (4)

$$\frac{dk}{dX} = K\,\frac{\alpha+2\beta X}{\{(2\mu+\rho+2\gamma)(\delta+\alpha X+\beta X^2)+(2\mu+\rho)\gamma\}^2}$$

Putting D for $(2\mu+\rho+2\gamma)(\delta+\alpha X+\beta X^2)+(2\mu+\rho)\gamma$

$$\frac{d^2k}{dX^2}=2K\frac{\beta D-(\alpha+2\beta X)^2(2\mu+\rho+2\gamma)}{D^3} \tag{6}$$

When

$$X=X_p$$

$$\boldsymbol{\alpha}=\alpha+2\beta X_p$$

$$\boldsymbol{\delta}=\delta+\alpha X_p+\beta X_p^2$$

$$\frac{d^2X}{dX_p^2}=2K\frac{\beta D-\boldsymbol{\alpha}(2\mu+\rho+2\gamma)}{D^3}$$

In order that the current k, in the slide wire, shall be a linear function of the departure of the thermometer from a fixed temperature, the term in equation (3) containing $(X-X_p)^2$ must reduce to zero—hence placing $d^2k/dX_p^2=0$.

$$\beta\{(2\mu+\rho+2\gamma)\boldsymbol{\delta}+(2\mu+\rho)\gamma\}=\boldsymbol{\alpha}^2(2\mu+\rho+2\gamma)$$

$$\frac{\boldsymbol{\alpha}^2}{\beta}=\frac{(2\mu+\rho+2\gamma)\boldsymbol{\delta}+(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}$$

$$=\boldsymbol{\delta}+\frac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma} \tag{7}$$

It is of interest to note that

$$R_0\left(\boldsymbol{\delta}+\frac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}\right)$$

is the resistance of the circuit as measured from the thermometer with the battery shortcircuited.

From (2) when $X=X_p$ and

$$\boldsymbol{\alpha}=\alpha+2\beta X_p$$

$$\boldsymbol{\delta}=\delta+\alpha X_p+\beta X_p^2$$

$$k_p=\frac{E}{R_0}\cdot\frac{\boldsymbol{\delta}-\gamma}{(\rho+2\mu+2\gamma)\boldsymbol{\delta}+(2\mu+\rho)\gamma} \tag{8}$$

Substituting in (3) the values for k_p and dk/dX_p from (8) and (5), remembering that d^2k/dX_p^2 is equal to zero and neglecting higher powers of $(X-X_p)$, the series reduces to:

$$k=\frac{E}{R_0}\,\frac{1}{(2\mu+\rho+2\gamma)\,\delta+(2\mu+\rho)\gamma}\left\{\delta-\gamma+\frac{(2\mu+\rho)\gamma+(2\mu+\rho+2\gamma)\gamma}{(2\mu+\rho)\gamma+(2\mu+\rho+2\gamma)\,\delta}\,\alpha(X-X_p)\right\}$$

$$=\frac{E}{R_0}\,\frac{1}{(2\mu+\rho+2\gamma)\left(\delta+\dfrac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}\right)}\left\{\delta-\gamma+\frac{\gamma+\dfrac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}}{\delta+\dfrac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}}\,\alpha(X-X_p)\right\}$$

But $\dfrac{\alpha^2}{\beta}=\delta+\dfrac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}$ hence

$$k=\frac{E}{R_0}\,\frac{1}{(2\mu+\rho+2\gamma)\,\dfrac{\alpha^2}{\beta}}\left\{\delta-\gamma+\left(1-\frac{\delta-\gamma}{\alpha^2/\beta}\right)\alpha(X-X_p)\right\} \tag{9}$$

Since the current k through μR_0 is to be a linear function of the departure of the temperature of the dry bulb from a fixed temperature X_A, it is convenient at this place to impose the additional condition that $k=0$ when $X=X_A$. This requires that:

$$\delta-\gamma+\left(1-\frac{\delta-\gamma}{\alpha^2/\beta}\right)\alpha(X_A-X_p)=0$$

$$(\delta-\gamma)\frac{\alpha^2}{\beta}+\left\{\frac{\alpha^2}{\beta}-(\delta-\gamma)\right\}\alpha(X_A-X_p)=0$$

$$(\delta-\gamma)\left\{\frac{\alpha^2}{\beta}-\alpha(X_A-X_p)\right\}+\frac{\alpha^2}{\beta}\alpha(X_A-X_p)=0$$

$$\delta-\gamma=\frac{-\dfrac{\alpha^2}{\beta}\alpha(X_A-X_p)}{\dfrac{\alpha^2}{\beta}-\alpha(X_A-X_p)}$$

$$=\frac{-\alpha(X_A-X_p)}{1-\dfrac{\alpha(X_A-X_p)}{\alpha^2/\beta}} \tag{10}$$

After satisfying this condition the expression for k can be simplified to either of the forms:

$$k=\frac{E}{R_0}\,\frac{\left(1-\frac{\delta-\gamma}{\alpha^2/\beta}\right)\alpha}{(2\mu+\rho)(\delta+\gamma)+2\gamma\delta}(X-X_A) \tag{11}$$

$$\text{and } k=\frac{E}{R_0}\,\frac{\left(1-\frac{\delta-\gamma}{\alpha^2/\beta}\right)\alpha}{\frac{\alpha^2}{\beta}(2\mu+\rho+2\gamma)}(X-X_A) \tag{12}$$

Equation (12) is derived from (9) by substituting in (9)

$$\delta-\gamma=\left(1-\frac{\delta-\gamma}{\alpha^2/\beta}\right)\alpha\,(X_p-X_A)$$

as obtained from the first line of (10).

(11) follows from (12) since from (7)

$$\frac{\alpha^2}{\beta}(2\mu+\rho+2\gamma) = (2\mu+\rho+2\gamma)\,\delta+(2\mu+\rho)\gamma$$

$$= (2\mu+\rho)(\delta+\gamma)+2\gamma\delta$$

A nickel calorimeter thermometer serial number 77525 was chosen for this circuit. It had the following characteristics:

$$R_0 = 47.1569 \text{ ohm}$$

$$\alpha = .0042009$$

$$\beta = .000004623$$

From which if X_p is chosen as 25°C:

$$\alpha = .0044321$$

$$\delta = \delta + .107912$$

$$\alpha^2/\beta = 4.24899$$

From equation (10)

$$\delta-\gamma=\frac{-\alpha(X_A-X_p)}{1-\frac{\alpha(X_A-X_p)}{\alpha^2/\beta}}$$

Taking $X_A = -10.77$ and $X_p = 25°C$.

$$\delta - \gamma = \frac{.0044321(35.77)}{1 + \frac{.0044321(35.77)}{4.24899}} \tag{13}$$

$$= .152832$$

$$\text{And } R_0(\delta - \gamma) = 7.2071 \text{ ohms} \tag{14}$$

$$R_0\alpha^2/\beta = 200.369 \text{ ohms} \tag{15}$$

$$\text{Take } \rho R_0 = 50 \text{ ohms}$$

$$\mu R_0 = 75 \text{ ohms}$$

From the remark made after equation (7), δ and γ must have such values as to make the resistance as measured from the thermometer arm 200.369 ohms or:

$$R_0\left(\delta + \frac{(2\mu+\rho)\gamma}{2\mu+\rho+2\gamma}\right) = 200.269$$

Combining this with the value above for $R_0(\delta-\gamma)$ there finally results:

$$\delta R_0 = 142.813 \text{ ohms}$$

$$\gamma R_0 = 135.606 \text{ ohms}$$

from which

$$\delta = 3.02846$$

$$\delta = 2.92055$$

$$\gamma = 2.87563$$

Tabulating the quantities computed

δ	= 2.92055	δR_0	= 137.724
δ	= 3.02846	δR_0	= 142.813
γ	= 2.87563	γR_0	= 135.606
ρ	= 1.06029	ρR_0	= 50
μ	= 1.59044	μR_0	= 75
$\mu+\rho/2$	= 2.12058	$(\mu+\rho/2)R_0$	= 100

Referring to Fig. 8, the potential drop from D to C is:

$$E = R_0\rho(2j+k) \tag{16}$$

while from B to C it is:

$$R_0\rho(j+k) \tag{17}$$

which may also be written:

$$\frac{R_0\rho(2j+k)}{2}+\frac{R_0\rho k}{2}=\frac{E}{2}+\frac{R_0\rho}{2}k \tag{18}$$

which proves the statement made on page 32 of the general discussion as to the manner of variation of the potential of B.

$$\delta-\gamma=.152832$$
$$\alpha^2/\beta=4.24899$$
$$\alpha=.004432$$
$$2\mu+\rho+2\gamma=9.99242$$

Hence the approximate expression for the current k as obtained from (12) is:

$$k=\frac{E}{R_0}.000100633\ (X-X_A) \tag{19}$$

and the corresponding potential difference from F to A is:

$$\left(\mu+\frac{\rho}{2}\right)k=E\ (.000213400)(X-X_A) \tag{20}$$

From equation (2) the exact expression for this potential difference is:

$$Pd_\theta=\left(\mu+\frac{\rho}{2}\right)k=\frac{\delta-\gamma+\alpha X+\beta X^2}{\dfrac{2\mu+\rho+2\gamma}{\mu+\dfrac{\rho}{2}}(\delta+\alpha X+\beta X^2)+2\gamma}E \tag{2}$$

In Table 3, which follows, the column headed "T.S." gives the approximate straight line potential difference from F to A as computed from (20) and the column headed "Exact" gives the actual value as obtained from (2).

TABLE 3.

X	*T. S.*	*Exact*	*T. S.—Exact*
10	.004432 E	.004433 E	−.000001 E
20	.006566	.006566	.000000
30	.008700	.008700	.000000
40	.010834	.010833	+.000001
50	.012968	.012965	+.000003

The last column indicates the magnitude of the errors resulting from assuming a straight line relation. They are negligibly small.

CALCULATIONS FOR WET BULB CIRCUIT

It is now necessary to set up a circuit wherein a potential difference proportional to the departure of the wet bulb temperature from some fixed point is secured. Fig. 9 shows the diagram of connections for

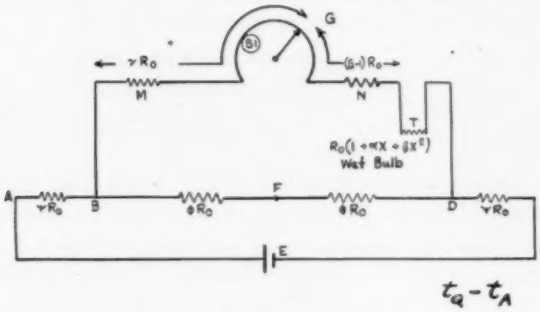

FIG. 9

the wet bulb circuit. There are several requirements that this potential difference must satisfy, namely:

1. It should be obtained from the same battery used to supply the dry bulb circuit so the outfit as a whole shall be independent of changes in the battery voltage.

2. One point should have the same potential as one end of the $(\theta_Q-\theta_A)$ slide wire in order that it may be possible to balance by moving just one brush.

3. $(t_Q-t_A)/(\theta_Q-\theta_A)$ may be as great as unity in a recorder which is read up to 100 per cent. In order therefore to make the drop across the slide wire greater than the potential difference to be balanced, the proportionality factor between potential difference and (t_Q-t_A) must not be greater than that between the drop across the slide wire and $(\theta_Q-\theta_A)$.

In Fig. 9 ϕR_0 and ϕR_0 are equal resistance coils, T is the thermometer of resistance $R_0(1+\alpha X+\beta X^2)$, $S1$ is a correcting slide wire, the purpose of which will shortly be described, γR_0 is a resistance including the coil M and that portion of the slide wire up to the point of contact G with the slider. $(\delta-1)R_0$ is a resistance including the coil N and the balance of the slide wire. ψR_0 and ψR_0 are resistance coils of equal value. The battery is connected as shown and maintains a potential difference E between A and H, where E has the same value as in the dry bulb circuit.

By a proper selection of the various resistances, commensurate with the characteristics of the thermometer, the potential between G and F may be made at all times proportional to the departure of the wet bulb temperature from a fixed value.

It is clear that, as the temperature goes up, the current through the upper branch tends to decrease, but if a thermometric material such as nickel is selected, whose resistance goes up more rapidly than the first power of the temperature, the resistances may be so chosen as to enable one to secure what is wanted, namely, that the potential difference between F and G shall be proportional to the temperature of the wet bulb above some fixed value.

The requirement 1 above is met by using the same battery for the two circuits and 2 is met because, as will be evident later from Fig. 10, the point F of Fig. 8 is at the same potential as the point F of Fig. 9. The proportionality factor is brought to the desired value by means of the coils ψR_0.

Attention has been called to the fact that all of the constant humidity lines do not intersect at a common point. Referring again to Fig. 5, it is noticed that for a dry bulb temperature of -10.77°C the corresponding wet bulb temperatures vary from -10.77° to almost -11.6°C in the range of humidities from .20 to 1.00. At 80 per cent humidity, for instance, the wet bulb temperature for -10.77°C dry bulb is -11.28° and the ratio we really want the recorder to indicate is

$$\frac{t_0+11.28}{\theta_0+10.77}$$

So in Fig. 9 instead of having G a fixed point, it is actually made movable over a range of approximately .8° and in accordance with the curve of Fig. 6. When the humidity is 80 per cent, for example, G must be at such a point that the bridge is balanced at -11.28° but when the humidity is 20 per cent the position of G must correspond to a balance temperature of -10.77°. Although this calls for a graded slide wire, only a very low accuracy is needed; an error of 5 per cent producing an effect equivalent to an error of .04°C in the wet bulb temperature. The introduction of this slide wire demands no additional balancing operation, as its position is a function of the humidity only, so that it need merely be mounted on the same disc as the slide wire of the dry bulb circuit and travel with it. Also the contact on this correcting slide wire does not enter as an error if it should vary.

The proof of the correctness of the wet bulb circuit follows. In Fig. 9 the potential difference between A and H is E. The resistance from B to D is:

$$\frac{2\phi(\gamma+\delta+\alpha X+\beta X^2)}{2\phi+\gamma+\delta+\alpha X+\beta X^2}R_0 \tag{22}$$

If the potential difference from B to D is denoted by $2e$ then:

$$e=\frac{E}{2}\,\frac{\dfrac{2\phi(\gamma+\delta+\alpha X+\beta X^2)}{2\phi+\gamma+\delta+\alpha X+\beta X^2}}{2\psi+\dfrac{2\phi(\gamma+\delta+\alpha X+\beta X^2)}{2\phi+\gamma+\delta+\alpha X+\beta X^2}} \tag{23}$$

which reduces to:

$$e=\frac{E}{2}\,\frac{\phi(\gamma+\delta+\alpha X+\beta X^2)}{2\psi\phi+(\psi+\phi)(\gamma+\delta+\alpha X+\beta X^2)} \tag{24}$$

The potential drop from B to F is e and that from B to G is:

$$\frac{2\gamma e}{\gamma+\delta+\alpha X+\beta X^2}$$

so from F to G it is

$$V=\left(1-\frac{2\gamma}{\gamma+\delta+\alpha X+\beta X^2}\right)e = e\left(\frac{\delta-\gamma+\alpha X+\beta X^2}{\gamma+\delta+\alpha X+\beta X^2}\right) \tag{25}$$

This combined with the expression for e, (24) gives:

$$V=\frac{E}{2}\left\{\frac{\delta-\gamma+\alpha X+\beta X^2}{\gamma+\delta+\alpha X+\beta X^2}\right\}\left\{\frac{\phi(\gamma+\delta+\alpha X+\beta X^2)}{2\psi\phi+(\psi+\phi)(\gamma+\delta+\alpha X+\beta X^2)}\right\}$$

which simplifies to:

$$V=\frac{E}{2}\,\frac{\phi(\delta-\gamma+\alpha X+\beta X^2)}{2\psi\phi+(\psi+\phi)(\gamma+\delta+\alpha X+\beta X^2)} \tag{26}$$

which may also be written:

$$V=\frac{E}{2}\,\frac{\phi}{\psi+\phi}\,\frac{\delta-\gamma+\alpha X+\beta X^2}{\dfrac{2\psi\phi}{\psi+\phi}+\delta+\gamma+\alpha X+\beta X^2} \tag{27}$$

Developing in a Taylor's Series, as before, in the neighborhood of $X = X_p$

$$\frac{dV}{dX} = \frac{E}{2}\,\frac{\phi}{\psi+\phi}\,\frac{D(\alpha+2\beta X)-(\delta-\gamma+\alpha X+\beta X^2)(\alpha+2\beta X)}{D^2}$$

Where for convenience

$$D=\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma+\alpha X+\beta X^2$$

$$\frac{dV}{dX} = \frac{E}{2}\,\frac{\phi}{\psi+\phi}\,(\alpha+2\beta X)\frac{\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma+\alpha X+\beta X^2-(\delta-\gamma+\alpha X+\beta X^2)}{D^2}$$

$$= \frac{E}{2}\,\frac{\phi}{\psi+\phi}\,(\alpha+2\beta X)\frac{\frac{2\psi\phi}{\psi+\phi}+2\gamma}{D^2} \tag{28}$$

Putting K for the constant factor

$$\frac{E}{2}\,\frac{\phi}{\psi+\phi}\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)$$

$$\frac{dV}{dX} = K\frac{\alpha+2\beta X}{D^2} \tag{29}$$

Place $X = X_p$ in (29) and substitute:

$$\alpha=\alpha+2\beta X_p$$

$$\delta=\delta+\alpha X_p+\beta X_p^2$$

$$\frac{dV}{dX_p} = \frac{E}{2}\,\frac{\phi}{\psi+\phi}\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\frac{\alpha}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^2} \tag{30}$$

From (29)

$$\frac{d^2V}{dX^2} = K\frac{2\beta D^2-2D(\alpha+2\beta X)^2}{D^4}$$

$$= K\frac{2\beta D-2(\alpha+2\beta X)^2}{D^3}$$

$$= K\frac{2\beta\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma+\alpha X+\beta X^2\right)-2(\alpha+2\beta X)^2}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma+\alpha X+\beta X^2\right)^3}$$

$$\frac{d^2V}{dX_p^2}=\frac{E}{2}\,\frac{\phi}{\psi+\phi}\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\frac{2\beta\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)-2\alpha^2}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^3}$$

From (27)

$$V_p=\frac{E}{2}\,\frac{\phi}{\psi+\phi}\,\frac{\delta-\gamma}{\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma} \tag{31}$$

Hence the Taylor's Series becomes:

$$V=\frac{E}{2}\,\frac{\phi}{\psi+\phi}\left[\frac{\delta-\gamma}{\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma}+\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\frac{\alpha}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^2}(X-X_p)\right.$$

$$\left.+\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\frac{2\beta\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)-2\alpha^2}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^3}(X-X_p)^2+\cdots\right]$$

To eliminate the term in $(X-X_p)^2$ it is necessary to make

$$2\beta\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)=2\alpha^2$$

Or

$$\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma=\frac{\alpha^2}{\beta} \tag{33}$$

The left side of this equation is the resistance of the circuit measured from the thermometer and with the battery shortcircuited so that this requirement is the same as that in equation (7) for the dry bulb circuit. As a matter of fact it can be shown that these equations are equivalent to requiring that the temperature coefficient of the temperature coefficient (β/α) of the circuit as measured from the thermometer shall be numerically equal to the temperature coefficient itself.

Another condition imposed is that, when the temperature of the wet bulb is $X = X_A$, $V = 0$. Hence

$$0 = \frac{E}{2}\,\frac{\phi}{\psi+\phi}\left[\frac{\delta-\gamma}{\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma} + \left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\frac{\alpha}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^2}(X_A-X_p)\right]$$

$$\delta-\gamma = -\frac{\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\alpha}{\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma}(X_A-X_p)$$

$$= \frac{\frac{2\psi\phi}{\psi+\phi}}{\alpha^2/\beta}(X_p-X_A)$$

$$= \left(\frac{\alpha^2}{\beta}-\delta+\gamma\right)(X_p-X_A)\frac{\beta}{\alpha}$$

$$= \frac{\alpha^2}{\beta}(X_p-X_A)\frac{\beta}{\alpha} - (\delta-\gamma)\,(X_p-X_A)\frac{\beta}{\alpha}$$

$$\delta-\gamma = \frac{\alpha(X_p-X_A)}{1+\frac{\beta}{\alpha}(X_p-X_A)} \tag{34}$$

Satisfying equation (33) to eliminate the $(X-X_p)^2$ term, neglecting higher powers, and substituting the value of $\delta-\gamma$ from the second line of (34), the Taylor's Series becomes:

$$V = \frac{E}{2}\,\frac{\phi}{\psi+\phi}\left[-\frac{\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\alpha}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^2}(X_A-X_p) + \frac{\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)\alpha}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^2}(X-X_p)\right] \tag{35}$$

$$= \frac{E}{2}\,\frac{\phi}{\psi+\phi}\left[\frac{\left(\frac{2\psi\phi}{\psi+\phi}+2\gamma\right)}{\left(\frac{2\psi\phi}{\psi+\phi}+\delta+\gamma\right)^2}\alpha(X-X_A)\right]$$

and substituting from (33) and (34)

$$V=\frac{E}{2}\,\frac{\phi}{\psi+\phi}\,\frac{\alpha(X-X_A)}{\delta+\gamma+\dfrac{2\psi\phi}{\psi+\phi}+\alpha(X_p-X_A)}$$

When $X_p=25$

$$V=\frac{E}{2}\,\frac{\phi}{\psi+\phi}\,\frac{\alpha(X-X_A)}{\delta+\gamma+\dfrac{2\psi\phi}{\psi+\phi}+\alpha(25-X_A)} \tag{36}$$

where

$$\frac{\alpha^2}{\beta}=\frac{2\psi\phi}{\psi+\phi}+\gamma+\delta$$

$$\delta-\gamma=\frac{\alpha(25-X_A)}{1+\dfrac{\beta}{\alpha}(25-X_A)}$$

$$\alpha=\alpha+2\beta(25)$$

$$\delta=\delta+\alpha(25)+\beta(25)^2$$

Thermometer serial number 77526 is to be used in this circuit and has the following characteristics:

$$R_0=47.5120$$

$$\alpha=.004216$$

$$\beta=.00000452$$

$$\alpha=\alpha+2(25)\beta$$

$$=.004216+2(25).00000452$$

$$=.004442$$

$$\delta=\delta+\alpha(25)+\beta(25)^2$$

$$=\delta+25(.004216)+(25)^2(.00000452)$$

$$=\delta+.108225$$

$$\frac{\alpha^2}{\beta}=\frac{(.004442)^2}{.00000452}$$

$$=4.3653$$

Substituting in (36)

$$Pd_t = V = \frac{E}{2}\,\frac{\phi}{\psi+\phi}(.00098182)(X-X_A) \tag{37}$$

This approximate equation agrees with the actual values as closely as does the dry bulb whose results are given in Table 3. Here Pd_t is the potential difference across the wet bulb circuit. The coefficient of $(X-X_A)$ must be the same as that of $(X-X_A)$ in (20), therefore:

$$\frac{\phi}{\psi+\phi} = .4347$$

Choosing $\psi R_0 = 100$ ohms

$\psi = 2.1047$

Then $\phi = 1.6185$

$\phi R_0 = 76.898$

As previously stated the slider **S1** is put in to take care of the failure of the constant humidity lines to intersect at one point, and the corrections must be in accordance with Fig. 6. The range of values there is from $-11.59°$ to -10.77°C, but in the curves as originally drawn when making the computations the lower limit was taken as -11.58°C.

From equation (26)

$$\delta+\gamma = -\frac{2\psi\phi}{\psi+\phi} = 2.5355$$

For $X_A = -10.77$

$$\delta-\gamma = \frac{\alpha(25-X_A)}{1+\frac{\beta}{\alpha}(25-X_A)} = .15331$$

$\delta = 1.3444$ $\quad \delta R_0 = 63.875$

$\gamma = 1.1911$ $\quad \gamma R_0 = 56.591$

Similarly for $X_A = -11.58$°C.

$\delta-\gamma = .15666$

$\delta = 1.3461$ $\quad \delta R_0 = 63.955$

$\gamma = 1.1894$ $\quad \gamma R_0 = 56.512$

THE COMPLETE CIRCUIT

The final arrangement of connections is shown in Fig. 10. This is obviously merely a combination of the two circuits previously discussed.

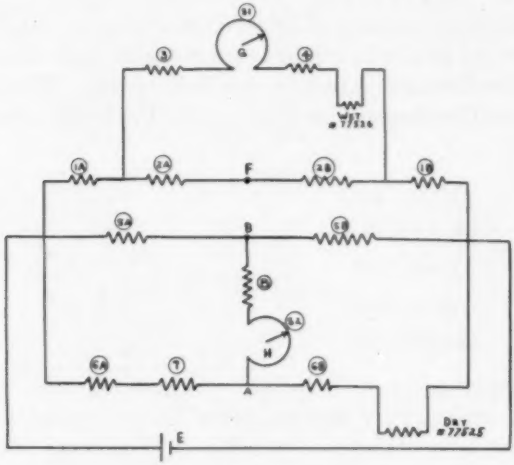

FIG. 10

$$5A = 5B = 50\Omega$$

At 20% Humidity $\dfrac{Pd_t}{Pd_0} = .6500$

$$8 = 40\Omega$$

$$S2 = 35\Omega$$

$$6B = 6A = (\delta - 1)R_0 = 1.9205 \times 47.157 = 90.567$$

$$7 = 135.61 - 90.567 = 45.039$$

$$3 = \gamma R_0 \quad = 56.611$$

(11.58)

$$S1 = \gamma R_0 \quad - \gamma R_0 \quad = .079513$$

(10.77) (11.58)

$$4 = (\delta - 1)R_0 \quad = 11.221$$

(10.77)

Coil 8 is inserted to make $S2$, the main slide wire, cover only the range actually used. In the lowest branch the two coils $6A$ and 7 are used

instead of one because the essential requirement seems to be the difference of resistance between the left and the right side. Therefore 6*A* and 6*B* are specified as matched coils but without very rigorous limits as to absolute values and 7 is of such value as to make the difference correct.

The operation of this instrument is rather simple. The dry bulb thermometer in the lower circuit affects the circuit in such a manner that the potential difference from *F* to *A* is at all times directly proportional to the departure of the temperature from −10.77°C. In the upper circuit the potential difference from *F* to *G* is at all times directly proportional to the departure of the wet bulb temperature from t_A where t_A has a value from −11.59°C to −10.77°C and depends only upon the humidity. Slide wire *S1* takes care of this latter term and is mounted on the same disc as the humidity slide wire *S2*, hence when the recorder is adjusting the slide *S2* to the proper humidity, it is also setting the correcting slide wire *S1* to the proper value. The recorder galvanometer connects from *G* to *H* and a balance is secured by adjustment of *S2*.

The finished instrument was checked at humidities of 30, 40, 60, and 80 per cent and at dry bulb temperatures of 10, 20, 30 and 40°C.

TABLE 4.

Humidity Equivalent to Dry and Wet Bulb Resistances	Dry Bulb Temperature	Humidity as Recorded
30 per cent	10°C	30.05
	20	30.05
	30	30.10
	40	30.00
40 per cent	10	40.03
	20	40.00
	30	40.00
	40	40.00
60 per cent	10	59.90
	20	59.93
	30	60.00
	40	60.03
80 per cent	10	80.00
	20	80.00
	30	80.00
	40	79.80

This was done by computing the resistance of the two thermometers at the temperatures (t_{SL}) listed in Table 1 and then substituting, for the thermometers, resistance boxes set to these values.

Table 4 below shows to what extent the recorder record checked with the calculated humidity values.

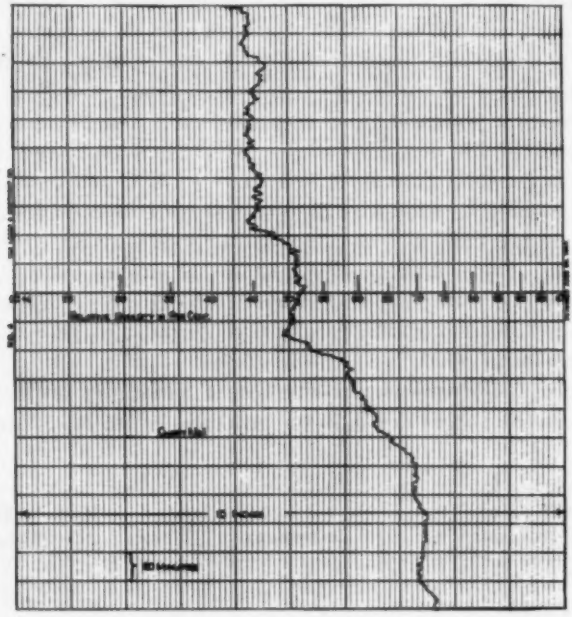

CHART 1

Chart No. 1 and Chart No. 2 are facsimiles of actual records of the instrument. As no special paper had at that time been printed, the humidity scale is shown at one point only on each chart.

MAINTAINING WET THERMOMETER BULB

Maintenance of the proper wet bulb condition has apparently been a troublesome feature with all forms of humidity indicators and recorders. Various methods have been employed. In a method devised by Cramer, U. S. Patent No. 871,163, the usual wick is done away with entirely on the assumption that the sole function of the wick is to obtain some water whose surface is large compared to its volume, and that the same effect can be obtained by finely atomizing the water.

To carry out this idea a compressed air operated atomizer is mounted at the top of a pipe and sends a fine spray of water down the pipe which is open at both ends. The atomizer also induces a draft of air and the air and water pass down together, the former evaporating and after a

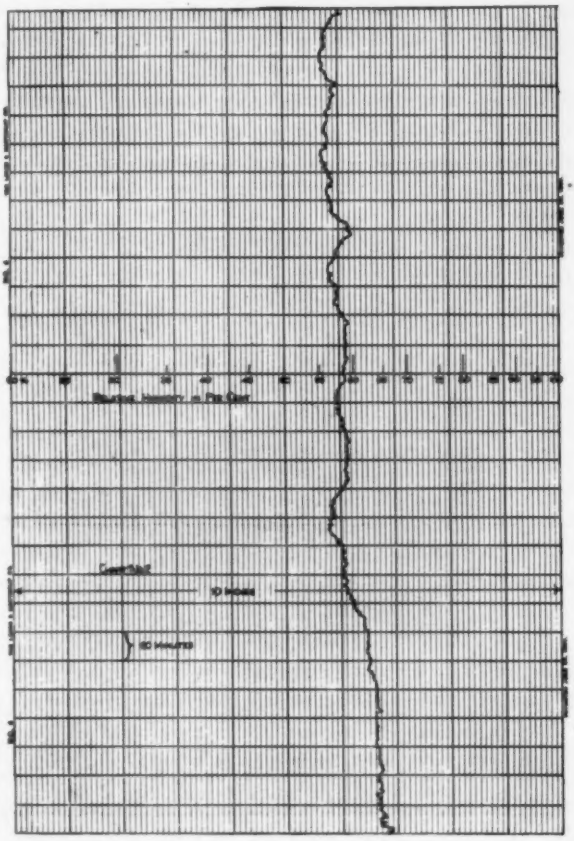

CHART II

while presumably being cooled down to the proper wet bulb temperature, at which time it is allowed to impinge upon the thermometer.

In another device due to Cramer and Hodge, U. S. Patent No. 968,133, there is employed a long wick in the form of a muslin strip attached to two rollers immersed in water. This wick folds over the

wet bulb thermometer. As the wick becomes dirty a clean portion is unrolled from one roller and the dirty portion rolled on the other. While it is practicable to accomplish this winding automatically it seems unnecessary as experience indicates that a small shift of the muslin once a day is sufficient.

A third device for wetting the wick and drawing air over it is illustrated in Fig. 11. This apparatus, referred to by E. B. Wheeler in the article previously cited, was used as a standard against which to check the ability of the other methods to produce a proper wet bulb temperature. This was chosen because equally low wet bulb temperatures could only be secured by placing wet bulbs transversely in front of a fan.

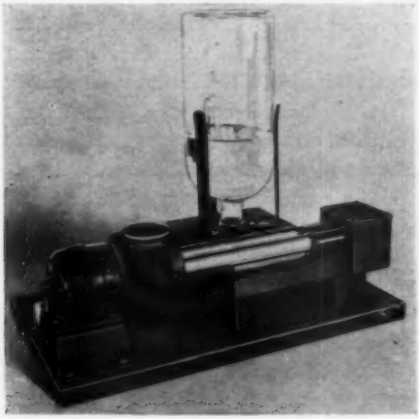

FIG. 11

For the purpose of testing these devices two calorimeter thermometers were selected which matched each other very closely and a recorder rewired to record their difference in temperature. With this arrangement differences of .1°C were readily and certainly observable. Employing the wind tunnel depicted in Fig. 11 and using two dry bulbs one in each tube, there were temporary and unsystematic deviations from equality which amounted to as much as .2°C. Placing both thermometers in the same tube this difference disappeared. When the two bulbs were wet but in different tubes, the deviations were not over .1°C. It seems plausible to explain this greater constancy of the wet bulb by the additional lag introduced by the wick covering.

Mr. W. B. Hodge, of the Parks-Cramer Company, kindly loaned a wet bulb device of the atomizer type. As first set up the wet bulb read about .7°C too high. It finally developed that about half of this error was due to failure on our part to jacket the instrument, and the other half due to the fact that the water supplied for spraying was not at the wet bulb temperature. After lagging the case with felt and exposing the feed water to the exhaust gases, this error was very materially reduced. The device was allowed to run for a long time and gave a variable error of from about .2°C too low to an equal amount too high, the magnitude seemingly dependent upon the humidity of the air being measured. From some rough calculations it seems likely, though not certain, that the compressed air used to operate the atomizer was sufficient in amount to alter the wet bulb temperature of the atmospheric air drawn in. There is little doubt that by using only enough compressed air to atomize the water and by introducing a small blower to draw the air through the pipe that the method would prove satisfactory.

An advantage of this method is that any failure to operate is immediately evident. As long as there is mist discharged from the pipe the device is operating correctly. On the other hand the apparatus uses one or two gallons of water a day and completely saturates a large volume of air. Investigation of this method was not carried farther because for present purposes it was essential that the humidity of the room under test should not be altered by the method of test. If necessary, however, to employ this method under the conditions imposed, provision can be made for discharging the exhaust gases out doors.

The method employing a continuous wick worked well at the first trial. With a not particularly clean wick and tap water contained in a rusty pan, the apparatus gave the wet bulb temperature as closely as could be read on the recorder. Scrupulous cleanliness in itself does not seem important. As long as the wick was moist the readings were correct. It was found that advancing the wick one inch a day was sufficient.

RESEARCH DEPARTMENT,
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Relative energy-values of various ion-lattices.—The ions in question are supposed to be force centers, acting on each other with a field which is the sum of the electrostatic field and a repulsion varying as the inverse nth power of the distance; and it may also be assumed that a field F acting upon an ion makes it a dipole of moment αF. Hund says that he has shown that the three arrangements of positive and negative ions, so grouped that each ion of one sign has neighbors exclusively of the other sign—viz the CsCl type in which each ion is surrounded by 8 of the opposite sign at the corners of a cube, the NaCl type in which each is surrounded by 6 at the corners of an octahedron the ZnS type in which each is surrounded by 4 at the corners of a tetrahedron—have relative energy-values depending on n; for small values of n the ZnS type is most stable, for medium values the NaCl type, for high values the CsCl type. Similar conclusions are reached for lattices of divalent metals. Hund thinks that the substances of which the molecules go integrally into the crystal lattice are distinguished by large values of α, and that this may also be responsible for lattices in which a stratum of one sort of ion is sandwiched between close-lying strata of the other kind.—[F. Hund, Göttingen, Phys. ZS., *26*, pp. 683–85; 1925.]

KARL K. DARROW

Metastable states of argon and neon identified by absorption experiments.—The experiments are performed by sending light from discharge in Ar or Ne through a tube containing the same gas, either unexcited, or excited by the same current (though less violently because of differences in shape between the two tubes). Lines which are particularly weakened by the excited gases may correspond to transitions terminating in a metastable state; for the atoms which absorb such a line are initially in the state in which the transition responsible for the line terminates, and if there are many such atoms it may mean that the state is one from which they cannot spontaneously return to the normal state. Previous experiments on Ne (This Journal, *11*, 146) indicated that the S_3 and S_5 states are metastable, which was confirmed by the analysis of the spectrum (for $j=0$ in the S_3 state, 2 in the S_5 state and 0 in the normal state). The present experiments on Ar likewise pick out certain metastable states, but the spectrum has not been analyzed. Using a commutator so as to excite the radiating gas at a variable interval T after the excitation is withdrawn from the absorbing gas, Meissner determines what is the greatest value of T compatible with perceptible absorption. This interval, which is supposedly of the order of magnitude of the duration of the metastable state, is found to be about $4 \cdot 10^{-3}$ second for two lines.—[K. W. Meissner, Frankfurt; Phys. ZS., *26*, pp. 687–89; 1925.]

KARL K. DARROW

RECORDING SMALL PRESSURE DIFFERENCES

By Irving B. Smith

The present availability of sensitive and accurate instruments for recording the resistance of electrolytes suggests their use for various purposes other than the actual determination of electrolytic resistance. One such application is to the recording of small pressure differences.

Referring to Fig. 1, the U-tube *A* of glass, bakelite, or other insulating material is partially filled with an electrolyte *B*. Two wires of platinum

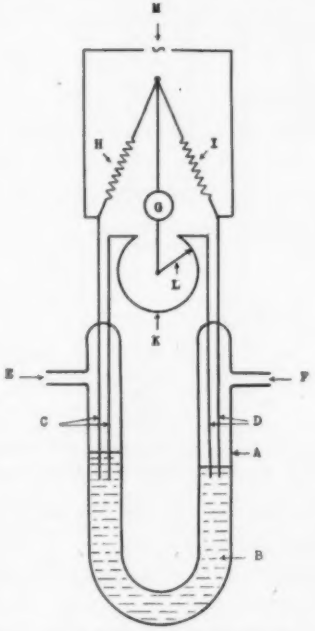


Fig. 1

C are sealed into one arm of the U-tube and two similar wires *D* sealed into the other arm. The wires should be coated with platinum black in the usual manner.

The resistance coils *H* and *I* constitute two arms of a Wheatstone bridge and the platinum wires *C* and *D*, together with portions of th

slide wire K, constitute the other two arms. The alternating current source M and alternating current galvanometer G are connected as shown. The slider L may be adjusted manually or automatically to balance the bridge. A 60-cycle alternating current circuit is usually employed as a source of current when the adjustment is automatic as in a recorder.

The difference in pressure between E and F manifests itself in a difference in level of the liquid in the two arms of the U-tube, and a proper calibration of the slide wire K serves to measure the pressure difference.

To demonstrate the order of sensitivity of such a device the level of the liquid in the U-tube was changed by lowering the U-tube pro-

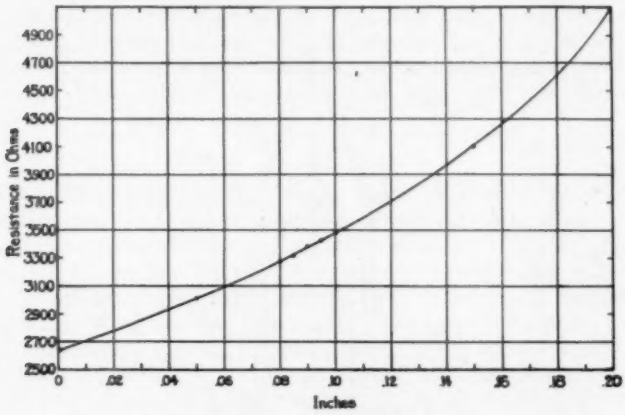


FIG. 2. *Change in Electrolytic Resistance with Change in Level of Liquid, Electrolyte, Dilute Hydrochloric Acid.*

gressively with a micrometer screw, and the resistance between the pair of wires C was measured for each level.

In Fig. 2 is plotted a curve showing the resistance for each change in level.

Starting with a position where the two wires C were immersed to a depth of approximately 5/16″ and setting the micrometer reading at zero for this level, the screw was gradually turned and the change in liquid level noted from the micrometer reading.

A smooth curve through the checked points departs a maximum distance corresponding to a change in level of .001″. Changing the direction of approach to any level results in a lag of less than .001″,

and is the chief source of error causing the points to depart from a smooth curve.

The sensitivity of setting depends largely upon the type of detector employed and the length of slide wire.

Using a Kohlrausch Bridge, a Vreeland Oscillator and a telephone, a difference in lefel of .00003″ could be detected. Employing a portable form of conductivity bridge, a 60 cycle circuit and a pointer galvanometer, a change in level of .003″ was measurable.

The sensitivity, when using a recorder, would depend of course upon the particular type of recorder employed, but with the most suitable one a sensitivity approaching that for the portable conductivity bridge might be attained.

To avoid errors from temperature change the U-tube may be held at a constant temperature, or an electrolyte chosen having a negligible temperature coefficient.

If measurements were made over a considerable period of time, an error may arise from evaporation of liquid.

The sensitivity and accuracy in some instances can be increased by lessening the depth of immersion of the wires. The magnitude of this change in sensitivity is indicated by the departure of the curve in Fig. 2 from a straight line.

THE LEEDS AND NORTHRUP CO.,
PHILADELPHIA, PA.

Secondary electron Emission from de-gassed Platinum.—Tingwaldt repeated the well-known experiments of Austin and Starke and of others, which had shown that the secondary electron emission due to an incident electron-stream of fixed intensity increases with the angle of incidence of the latter. He de-gassed his platinum target, as well as the other metal parts of his apparatus, by heating them in high vacuum with electric currents. He then obtained the remarkable result, that with primary electrons accelerated by 12, 20, 100 or 500 volts there is no variation of secondary electron emission with angle of incidence! With primary electrons accelerated by less than 12 volts the emission increased with the obliquity of incidence, but this increase could be annulled by raising the target to a potential 1.8 volt higher than the surrounding walls, so that he ascribes it to a double-layer on the target surface. No control experiments with unheated platinum are mentioned.—[C. Tingwaldt (Landwirt. Hochschule, Berlin—ZS. f. Phys., *34*, pp. 280–84; 1925.]

KARL K. DARROW

Speculations on Encounters between Electrons and Atoms.—This article is described towards its end as "of a hypothetical and preliminary character" and in an added note inserted after the experiments of Bothe and Geiger (cf. This Journal, *12*, 269) as "an attempt now without apparent prospect of success." Its most important feature is probably, therefore, the emphasis laid upon certain phenomena difficult to interpret. For instance, the transfer of energy from alpha-particles to atoms and the resulting detachment of electrons from atoms by alpha-particles, which take place in about the amount predicted from the classical theory, apparently without allowance for the presumed necessity that the atom or atom-residue must be left in some definite *stationary state*; the difficulty in understanding how an atom could be transferred from one stationary state to another by an alpha-particle remaining in or near it so short a time; the capture of electrons by alpha-particles. It is suggested that some curious phenomena might be observed in the excitation or ionization of molecules by slow electrons, since the speed of the impinging electron may be comparable with those of the vibrating nuclei. In the added note Bohr intimates that he is prepared to give up "spatio-temporal pictures" altogether—whatever that may mean.—[N. Bohr (Copenhagen); ZS. f. Phys., *34*, pp. 142–57; 1925.]

KARL K. DARROW

Photographic Registration of Protons.—This was attempted by the method devised for alpha-particles by Michl: the particles strike a photographic plate (various usable kinds are specified) at angles of incidence exceeding 60°, and in the developed plate one sees with a microscope rows of dots extending over lengths which may attain nearly .05 mm. The particles in question, which come from a layer of paraffin bombarded by alpha rays from Po, and pass through a metal film thick enough to stop all alpha-particles before they reach the plate, are supposed to be hydrogen nuclei driven out of the paraffin by direct impacts of the alpha-particles. Similar tracks obtained when Al was bombarded are ascribed to protons resulting from disruptions of Al nuclei, while similar tracks obtained with lampblack (the experiment was expected to give a negative result) are attributed to impurities in the lampblack.—[M. Blau (Radium Inst., Vienna); ZS. f. Phys., *34*, pp. 285–95; 1925.]

KARL K. DARROW

A NEW METHOD FOR MEASURING THE ACCELERATION DUE TO GRAVITY

By Donald S. Piston and Albert L. Fitch

The method described herein was devised for the purpose of providing the students in our sophomore physics laboratory with a way of finding the acceleration due to gravity from a direct measurement of the time taken for a body to fall a certain distance. The body is allowed to slide down a wire stretched vertically between two spiral springs, which are set into vibration when the weight is released. (Fig. 1.) The number of vibrations made by the springs while the weight is falling the length of the wire may be ascertained by recording the vibrations on a sheet of paper which is slid past a pencil attached to the lower spring. The frequency of the springs may be calculated from the elasticity and mass, or it may be found by comparing with a tuning fork of known frequency. The frequency is of course the frequency of a longitudinal wave in the spring, the velocity of propagation of which is the square root of Young's modulus over the density. Since the springs are fastened at the ends, and the wire may be treated as rigid, the wave length is twice the length of the springs exclusive of the wire. A simple calculation shows that the frequency in vibrations per second is

FIG. 1
Arrangement of Apparatus

$$n = \tfrac{1}{2}\sqrt{k/M} \qquad (1)$$

in which k is the force required to stretch the spring a unit distance, and M is the mass of the springs. In this analysis the weight of the wire is supposed to be negligible with respect to the weight of the springs themselves. Of course, in using this formula we may be accused of an inconsistency on the ground that it is necessary to know the value of g to calculate k, but this gives us a way of checking the tuning fork method, at least.

In the apparatus as used in this laboratory, the mass of the springs was 149.5 grams, and the springs were stretched 14.6 cm by a load of

3 lbs., or 1362 grams. This gives for the frequency, by equation (1 11.7 vibrations per second. The value got by comparison with a larg tuning fork was 11.6 vibrations per second, so this gives us a goo check on the calibration of the fork, which was a large one with frequency of 8.9 vibrations per second.

The following table shows some of the measurements made b students in this laboratory and the values of g calculated therefrom

Distance fallen	Number of vibrations	Time of descent	Values of "g"
3.0 ft.	5.0	.431 sec.	32.4 ft./sec.^{2}
3.0	5.5	.474	26.8
4.0	6.0	.517	30.0
4.0	5.5	.474	35.6
5.0	6.5	.561	31.8
5.0	7.0	.602	27.6
6.0	7.0	.602	33.1
6.0	7.7	.665	27.0
Mean			30.5 ft./sec.^{2}
75 cm	4.5	.387 sec.	1000cm/sec.^{2}
100	5.3	.457	960
175	7.0	.602	970
200	7.4	.638	983
Mean			978 cm/sec.^{2}

DEPARTMENT OF PHYSICS,
UNIVERSITY OF MAINE,
ORONO, ME.

Dissociation and Fluorescence of Iodine Vapor.—As gaseous iodine displays a long series of bands with the band heads evidently converging upon a limit near 4995A, beyond (at shorter wave lengths than) which no bands are seen, it is inferred that absorption of a quantum of the convergence-frequency entails an intramolecular vibration of the I_2 molecule so great in amplitude that the molecule falls apart. This inference is strengthened by the fact that no fluorescence can be excited by irradiating the vapor with light of wave length below 4995. If true, the process in question involves a transfer of 2.5 equivalent volts to the dissociating molecule, whereas the heat of dissociation of I_2 is only 1.4. The difference may be energy of excitation of one of the resulting atoms; there is evidence from several sides (no individual piece of it very strong, however), that the I atom has a metastable state superior in energy by about 1.1 equivalent volt to the normal state.—[E. G. Dymond, Göttingen; ZS. f. Phys. *34*, pp. 553–61; 1925.]

KARL K. DARROW

A COMPARISON OF X-RAY AND WHITE LIGHT EXPOSURES IN PHOTOGRAPHIC SENSITOMETRY*

By R. B. Wilsey and H. A. Pritchard

The ordinary phenomena of photographic sensitometry with exposures to light are well known; the findings of Hurter and Driffield[1] and their methods of presenting and analyzing sensitometric data, have not been greatly modified by succeeding workers. More recently important additions to their methods were made by Nietz[2] in his study of the theory of development.

Comparatively little sensitometric work has been done with x-rays; contributions to this subject have been made by Wertheim-Salomonson,[3] Hodgson,[4] Allen and Laby,[5] Bloch and Renwick,[6] and Glocker and Traub.[7] As a rule the characteristic curve (density *vs.* log exposure) for x-ray exposures was found to have a straight line portion, as is the case with the white light curve; the x-ray curve generally had a long toe, extending to densities of one or higher. Photomicrographs of sections of developed films which had been exposed to x-rays showed a uniform distribution of the silver grains throughout the depth of the emulsion layer, whereas exposures to light showed a diminution in the number of developed silver grains in passing from the surface through the emulsion. Allen and Laby found the inertia point (intersection of the continuation of the straight line portion of the curve with the log-E axis) to be independent of the time of development, as is generally considered the case with white light exposures. Bloch and Renwick found the growth of density with time of development to follow the relation $D=D_\infty(1-e^{-kt})$. After constructing a photometer for measuring high densities, Jones[8] was able to show that the x-ray characteristic

* Communication No. 257 from the Research Laboratory of the Eastman Kodak Company.

[1] Hurter & Driffield Memorial Volume of Photographic Researches, pub. by Royal Photographic Society, 1920.

[2] A. H. Nietz, Monograph No. 2 pub. by Eastman Kodak Co., Theory of Development, 1922.

[3] I. K. A. Wertheim Salomonson, Proc. Konink. Akad. Wetensch. Amsterdam, *18*, p. 671.

[4] M. B. Hodgson, Am. J. Roent., *4*, p. 610; 1917.

[5] N. C. B. Allen and T. H. Laby, Nature *103*, p. 177; 1919.

[6] O. Bloch and F. F. Renwick, Trans. Far. Soc. *15*, *2*, p. 40; 1920.

[7] R. Glocker and W. Traub, Phys. Zeit., *22*, p. 345; 1921.

[8] L. A. Jones, J.O.S.A. & R.S.I. 7, p. 231; 1923.

curve had a shoulder and reached a maximum density, as do the curves for white light. There was disagreement on the comparative effects of x-rays and white light, and of various wave lengths of x-rays, on the slope of the characteristic curve.

The purpose of the present study was to compare the forms of the characteristic curves and the development phenomena of x-ray and white light exposures, applying the methods of Hurter and Driffield and of Nietz in analyzing the sensitometric data.

EXPERIMENTAL METHODS

In these experiments, x-ray and white light exposures were made on the same photographic material and carried through the same development procedure; the exposures were adjusted to give practically the complete characteristic curve in every case; a wide range of development times were used; and the data were analyzed in considerable detail to compare the exposure and development phenomena of x-ray and white light exposures.

The exposures were made in a non-intermittent sensitometer of the type designed by Jones.[9] The source of x-rays was a Coolidge tube operated at 60 kilovolts by an interrupterless transformer. The x-ray intensity could be held constant within two per cent.

The source of white light was a lamp box containing an electric lamp, and fitted with a diffusing glass window. The voltage was adjusted to give light of color temperature 2360°K. The intensity could be controlled to within one per cent.

The sensitometric strips were developed in an elon-hydroquinone developer in a water jacketed tray. The developer was kept at a constant temperature of 65°F by the circulation of water around the tray from a thermostat bath. The tray was rocked continuously in an irregular motion during development. The development times ranged from 1 to 16 or 32 minutes. Three strips were developed at each time, and their densities averaged to obtain the characteristic curve.

The densities were read by diffuse light with a Marten's polarization photometer; for densities higher than 1.5 a comparison density was used with the photometer to avoid the error due to scattered light at small angle readings. This photometric arrangement was carefully checked with the Jones high intensity densitometer before the densities of the sensitometric strips were measured.

[9] L. A. Jones, J. Frank. Inst., *189*, p. 303; 1920.
Phot. J. *60*, p. 80; 1920.

Characteristic curves were plotted from the observed data. The data were then smoothed by a process suggested to us by Mr. L. A. Jones. At each exposure, density values taken from the characteristic curves were plotted against development time. Smooth curves were plotted following these points; then at each development time, values were taken from these curves to replot the characteristic curves.

The data were then corrected for fog by a method which has been described in a previous paper.[10] In this method it is assumed that fog over the image is proportional to the mass of silver unaffected by exposure, and is given by the equation

$$D_f = \frac{D_m - D_\infty}{D_m} \cdot F$$

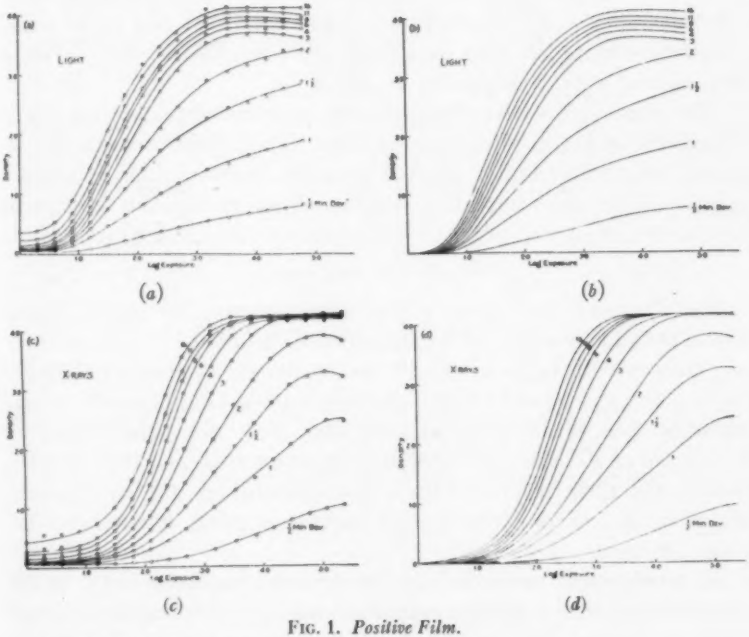


FIG. 1. *Positive Film.*

(a) White light characteristic curves, from observed data
(b) White light characteristic curves, smoothed and corrected for fog.
(c) X-ray characteristic curves, from observed data.
(d) X-ray characteristic curves, smoothed and corrected for fog.

Note: To avoid crowding, the characteristic curves for some of the development times have been omitted in the charts.

[10] R. B. Wilsey, Phot. J., *65*, p. 454; 1925.

where D_f is the deduction for fog over the image, F the fog density in an unexposed area, D_m the maximum density developable on the film, and D_∞ the image density which would be given by complete or infinite development of the exposed area considered. This fog correction fails to account for the effect of reaction products of development on fog, unless Bloch's[11] method of determining the fog, F, is used. It is also possible that the grains most susceptible to fog are apt to be most sensitive to exposure, and in this case also, the above fog deduction would be too great. In some of the experimental data, where rather high fog was obtained, there was evidence that the fog correction was excessive. However this method of correction for fog is much better than the practice of deducting a uniform fog from all the densities of a characteristic curve, and is the best that can be done at present, particularly where the fog, F, is measured on a large area at the end of the sensitometric strip rather than on a small protected area in the middle of the exposed area, as suggested by Bloch.

The effect of the smoothing process and the correction for fog is illustrated by Fig. 1. At *a* and *c* are shown the families of characteristic curves for positive film as plotted from the observed data; at *b* and *d* are the curves after smoothing and correcting for fog; the subsequent operations are carried out upon the smoothed corrected curves.

DISCUSSION OF THE DATA

Fig. 2 shows the sets of characteristic curves, for positive film, smoothed and corrected for fog, and other data derived from them, such as derivatives of the characteristic curves, density-time of development curves, and gamma-time of development curves. Fig. 3 shows similar data obtained on single coated x-ray film. Since the actual exposure values are of no particular interest in these experiments, their relative values, not their absolute values, are indicated by the log-exposure scales on the curves. The various features of these data will be discussed in turn.

As development proceeded, all the densities increased, until, at the heavier exposures, a definite maximum was reached; further development served only to increase the densities at shorter exposures. Furthermore, this maximum density (D_m) was practically the same for the x-ray exposures as for white light. This is the effect to be expected if the maximum density is that due to the total mass of silver available in the film, and is the limiting density reached when all the silver

[11] O. Block, Trans. Far. Soc., 19, *2*, p. 327; 1923.

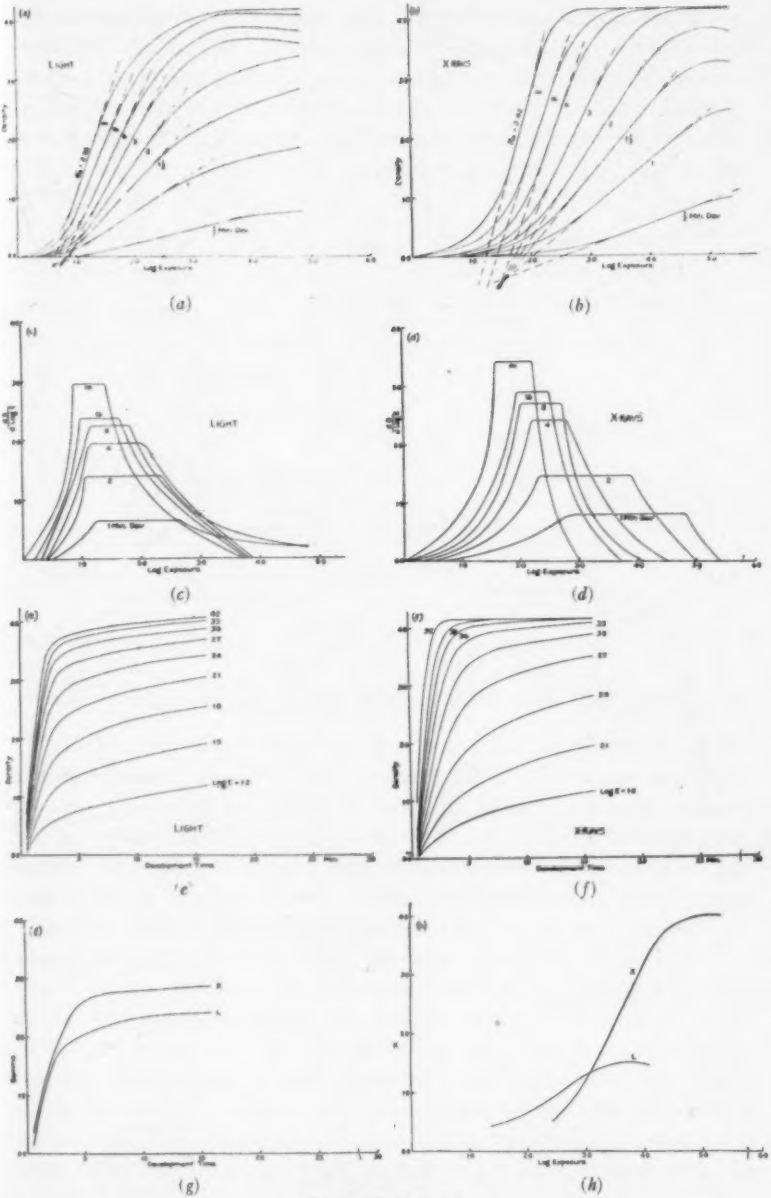


FIG. 2. *Positive Film.*

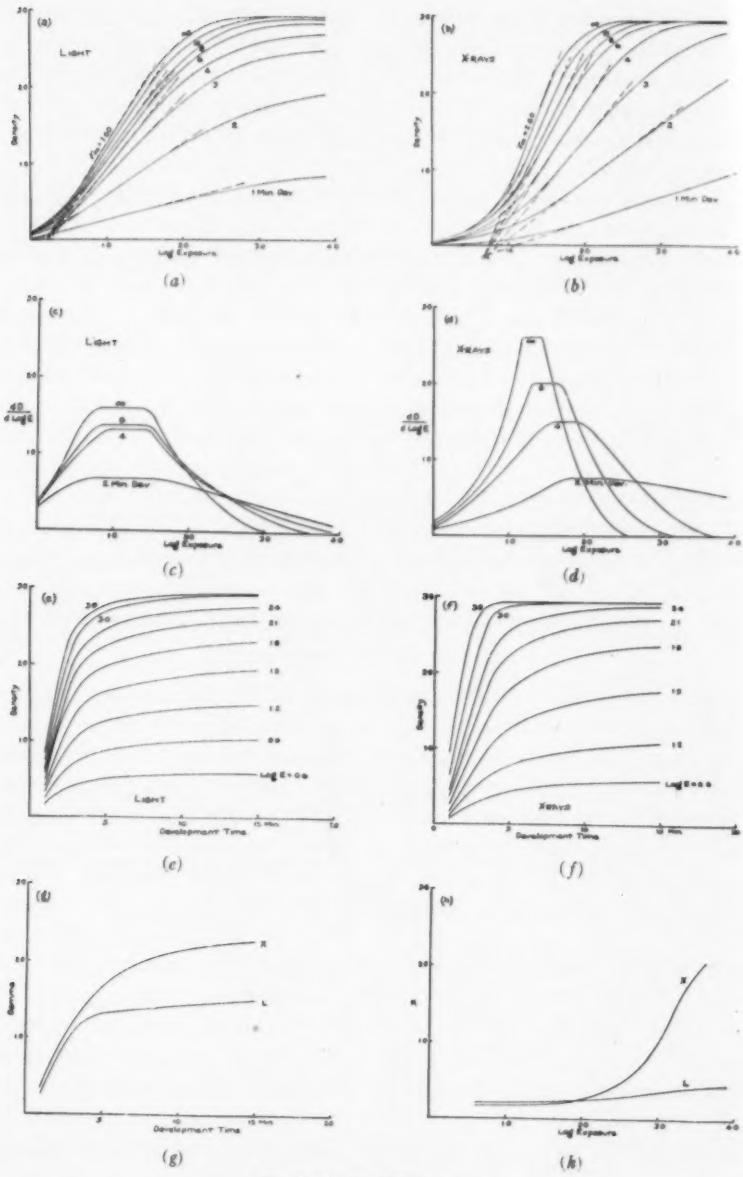


FIG. 3. *X-Ray Film (No. 1).*

halide in the emulsion layer has been affected by exposure and has been completely developed. To determine whether this was actually the case, analyses were made of the silver content, first in a piece of undeveloped x-ray film, and then in other pieces of film cut from the same sheet, one given a heavy x-ray exposure and the other a heavy exposure to light and developed to the maximum density. The results are recorded in the following table.

TABLE 1*

Experiment		Average density	Grams Ag per 100 cm²	Photometric constant
Experiment 1	Undeveloped film		0.0715	
	White light exposure	2.86	0.0717	0.0251
	X-ray exposure	2.75	0.0718	0.0261
Experiment 2	Undeveloped film		0.0685	
	White light exposure	2.80	0.0716	0.0256
	X-ray exposure	2.78	0.0690	0.0248

* We are indebted to Mr. Albert Ballard of this laboratory for the silver analyses.

It is apparent from these data that within experimental error, the maximum density observed with either white light or x-ray exposures was that due to the development of all the silver in the film. Photomicrographs were made of sections cut from films showing the maximum density, for both white light and x-ray exposures. The sections for both types of exposure show a uniform distribution of silver grains throughout the depth of the emulsion layer (Fig. 4), as would be expected if all the silver has been developed.

In order to check more accurately the equality of maximum density for the two types of radiation, suitable exposures were made with white light and x-rays on alternate strips cut from a single sheet of film, and developed to maximum density. The experiment was carried out on three kinds of film, positive film, single coated x-ray film, and a fast portrait film. In no case did the maximum density produced by x-rays differ from that for white light by more than 1.5 per cent. It

is entirely possible that in some cases, complicating conditions may prevent the development of all the silver in an emulsion so that the results reported here can not be assumed to be perfectly general.

Another interesting feature of the data is the effect of time of development upon the growth of density and upon the form of the characteristic curve. The changes occurring with development can be shown in several ways. On examining the x-ray characteristic curves, a progressive change in form of the curve with time of development is observed. The shortest development time shows a long toe, a straight line portion, and a shoulder which deviates but little from the straight line portion. As development proceeds, the higher exposures on the

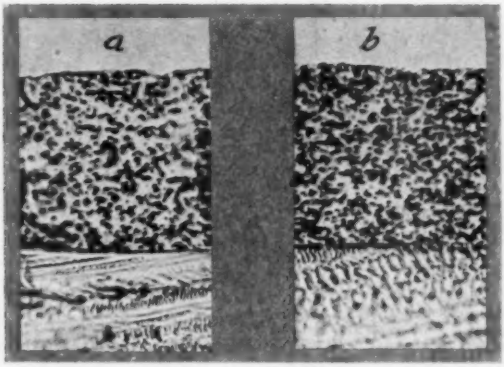


FIG. 4. *Photomicrographs of sections of x-ray film, exposed and developed to give maximum density.*
(a) Exposed to light
(b) Exposed to x-rays
(These photomicrographs were made for us by Mr. A. P. H. Trivelli.)

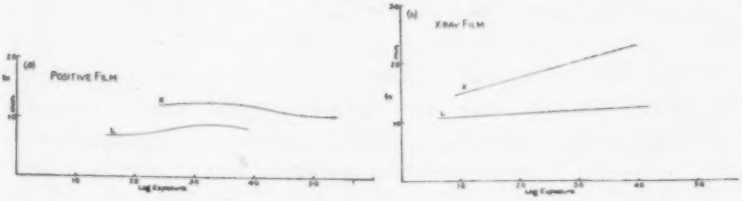
straight line portion go more and more into the shoulder; the toe of the curve gradually becomes part of the straight line portion, the result being that the straight line portion of the characteristic curve shifts toward the shorter exposures. These changes in form of the curve with development are shown more clearly by the derivative curves (Figs. 2*c*, 2*d*, 3*c*, 3*d*). Similar changes occur with the exposures to light, but in a much lesser degree. It is of interest to note how these changes are exhibited in the curves of density plotted against time of development; these curves show a considerable change in form as exposure is increased. The densities for the lighter exposures grow rather gradually with time

of development; for the heavier exposures the densities increase rapidly to a rather sharp bend and then gradually approach a limiting density.

It is apparent from inspection of the characteristic curves as well as of the derivative curves and the density-time curves that the law of constant density ratios did not hold over the whole range of exposures. One way of showing the failure of the law of constant density ratios is to apply to the density-time curves the Nietz development equation.

$$D = D_\infty(1 - e^{-k \log t/t_0})$$

This equation expresses the law of constant density ratios in case the parameters K and t_0 remain the same for the density-time curves at the various exposures; in such a case the density D at each time of development t is proportional to the limiting density D_∞ for that exposure. The curves for the different exposures would be identical in form, differing only in the absolute values of the densities. Any density-time of development curve could be derived from any other curve by multiplying each density throughout by a constant factor. When the Nietz equation was applied to the data, t_0 was found to vary but slightly for the various density-time curves (Fig. 5) while the velocity constant



(a) (b)

FIG. 5. *t_0 of the Nietz development equation, as a function of exposure. The small variations in t_0 show that most of the variations in the form of density-time of development curves are expressed by the velocity constant K.*

of development K showed a marked increase from the curves for low exposures to those for high exposures. This increase of K with exposure was greater for the x-ray exposures than for the white light exposures. In the case of the positive and x-ray films, the maximum value reached by K for the x-ray exposures was much higher than that for white light (Figs. 2h and 3h) whereas in the case of the portrait film the maximum value of K for x-ray exposures was only slightly higher than that for white light (Fig. 11c).*

* Evidence of an effect of exposure on the development velocity of silver halide grains was found in an experiment of Sheppard and Mees (Proc. Roy. Soc., A,76, p. 217, 1905) who found that "the grain receiving the most exposure is most reactive and starts development first."

That the effect upon velocity of development is really due to the exposure seems to be shown by the following fact. As exposure was increased, a point was reached where, by sufficient development, the maximum density, corresponding to all the silver in the film, could be developed. All the grains in the emulsion had been made developable. In the case of x-ray exposures all the grains throughout the depth of the emulsion had received sensibly the same exposure. Additional exposure enabled the maximum density to be developed in a shorter time; the resulting density-time curve was higher than the previous one up to the point where D_m was reached, and the velocity constant K was higher. Under these conditions, the only change impressed on the film had been in the exposure, and the result was clearly an increase in rate of development. The rate of development was affected not only by the

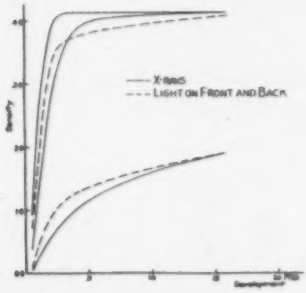


FIG. 6. *Positive film. Direct comparison of some density-time of development curves for x-ray and white light exposures.*

amount of the exposure, but by the kind of radiation making the exposure. The maximum development rate for x-ray exposures was found to be greater than that for white light, although in both cases all the silver in the film has been made developable.

The velocity constant K does not express all the differences between x-ray and white light exposures as regards progress of development. The three upper curves of Fig. 6 are for exposures sufficient to make all the silver in the film developable; the white light densities grow in a somewhat different manner from that of x-ray densities, and it is evident that the x-ray and white light density-time of development curves could not be made to coincide by any adjustment of the exposure. A similar effect was observed with x-ray film, but was not found with portrait film.

The above conclusions are not affected by the methods of treating the data in smoothing and in correcting for fog. No fog deduction is made for exposures sufficient to affect all the silver halide; and the effect of exposure on rate of development was shown just as definitely by the original data as by the smoothed data, as can be seen in Fig. 1.

It may be asked whether the observed effect may not be an optical effect, a variation in the relation between density and mass of silver. It is conceivable that if mass of silver were plotted in place of density, the curves would not show the variations which are interpreted as an effect of exposure on rate of development. Consider the family of x-ray characteristic curves of Fig. 1c, plotted from the observed data. The curve for 16 minutes' development shows the maximum density over the log E range 3.9 to 5.1. In this same exposure range, the curve for 2 minutes varies in density from 3.15 to 3.85, and there is no reason to doubt that the higher density contains more silver than the lower one. If in this exposure range development rate has not increased with exposure, then the mass of silver in the 16 minute sensitometric strip must increase in the same proportion from a log E of 3.9 to a log E of 5.1 as it does in the case of the 2 minute strip; in other words in the 16 minute strip, the mass of silver at a log E of 5.1 should be considerably higher than that at a log E of 3.9, although the densities are the same. To test this point analyses of the silver content were made in films given these two exposures and developed to give maximum density. A similar experiment was carried out with exposures to light. The results are recorded in the following table.

TABLE 2*

Exposure to	Log exposure (as per scales of Fig.1)	Maximum density D_m (observed)	Mass of Silver per 100 cm² in maximum density	Photometric constant	Mass of silver per 100 cm² in unexposed film
White light	3.6	3.90	.0493	.0126	
	4.8	4.05	.0490	.0121	
X-rays	3.9	3.97	.0499	.0126	
	5.1	4.00	.0498	.0124	
	Mean	3.98	.0495	.0124	.0502

*The silver analyses were made by Mr. Albert Ballard

It is clear that within the range of exposures used in the experiment, the maximum density corresponds to a fixed mass of silver per unit area regardless of the exposure; therefore the increase of exposure has produced an increase in the rate of development of silver as well as of density. Comparison of columns 4 and 6 of Table 2 shows also that within experimental error the maximum density is that due to the development of all the silver in the film.

When the exposure was not sufficient to affect all the silver halide, it was uncertain to what extent the variations in the velocity constant K were determined by the character and amount of the exposure, and how much they were affected by other factors, such as the reaction products of development and the distribution of the affected silver in the emulsion layer. However there is good reason for believing that the exposure was the chief factor in the observed variation in rate of development.

Increasing exposures to light progressively affect deeper layers of the emulsion, until all the halide is made developable. The effect is to increase the average diffusion path of the developer in reaching the silver halide, and of the reaction products in escaping from the film. The tendency would be to slow up the development, diminishing the velocity constant K.

Increasing exposures also increases the mass of silver to be developed within the same volume of emulsion, the effect being to exhaust the developer more rapidly and to increase the concentration of reaction products in the volume where the reaction is taking place. These actions would also tend to slow up development, diminishing the velocity constant K. However in the region of exposure where these effects are occurring, K was found to increase with exposure. It must be concluded therefore that in these experiments the variations in penetration and mass effects exerted less influence on rate of development than the increase in exposure. The important influence of exposure on development may also be illustrated in the following way. At the maximum rate of development of x-ray film (Fig. 3), all the silver in the film was developed in five minutes; four minutes development was sufficient to attain within one per cent of the maximum density; yet at a lower exposure, on the straight line portion of the characteristic curve, 15 minutes' development gave but 87 per cent of the limiting density for that exposure. In the latter case, the failure of any silver to develop within the first five minutes was not due to such phenomena as exhaustion of the developer, production of reaction products, diffusion,

swelling of the gelatine, etc. Similarly with positive film, a suitable exposure to x-rays enabled the maximum density to be fully developed in four minutes, whereas with more moderate exposures, development was not complete at 16 minutes. In the case of the one-grain-layer plates investigated by microscopic methods, it is wrong to assume that complete development of all the exposures is reached in a short time because of the thinness of the gelatine layer; development of the lower exposures would probably not progress much faster in a single-layer

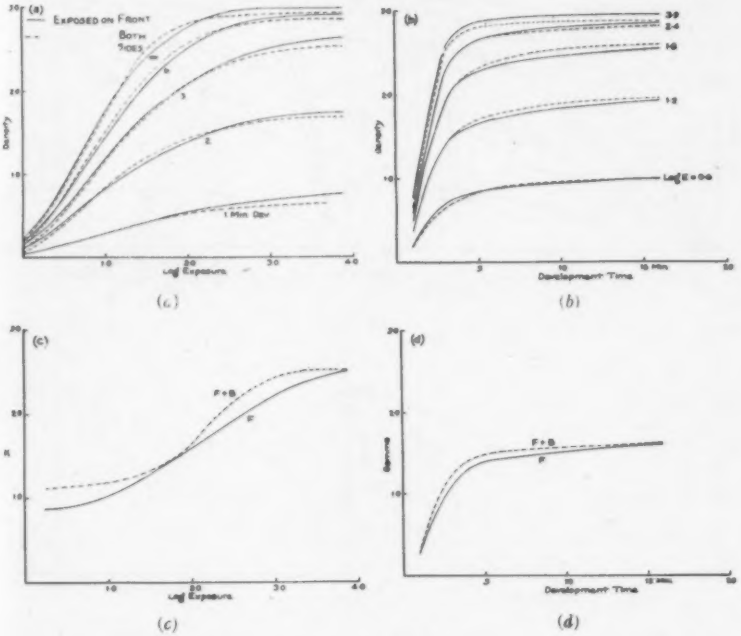


FIG. 7. *X-ray film (No. 1) exposures to white light, comparing the effects of of exposures on the front of the film with exposures equally divided between front and back.*

plate than in an ordinary multilayer plate of the same emulsion. Owing to the effects of exposure on development, partial development does not give the same relation between grains developed and the exposure as does complete development; exposure theories have not yet taken these development effects into account; therefore comparison between theory and experiment is not valid unless development is complete; adequate tests should be carried out to insure that such is the case.

Lüppo-Cramer[12] found that plates exposed through the back developed with nearly the same speed as plates exposed to the front; he concluded that many photographic effects were unjustly attributed to variations in the penetration of the light in the emulsion layer. Similar results were obtained in the present experiments. Figs. 8, 10, and 11 show comparisons of sensitometric data with exposures to the front and through the back of the film; Fig. 7 shows exposures on the front alone compared with equal exposures on both the front and back of the film.

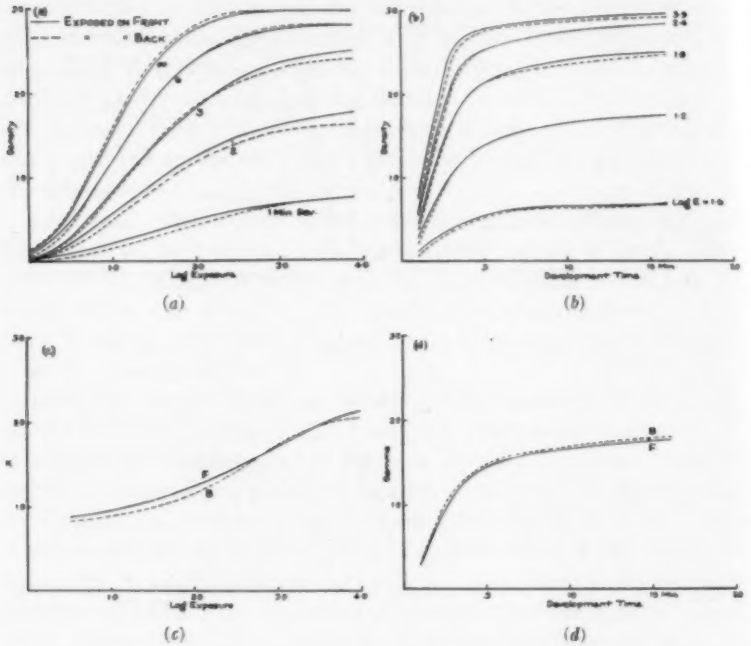


FIG. 8. *X-ray Film (No. 1); exposures to white light, comparing the effects of exposures on the the front of the film with exposures on the back of the film.*

These data support the conclusion of Lüppo-Cramer that the only definite differences between the effects of exposures on the front and exposures on the back of the film occur at the lower exposures for the shorter development times. The values of the velocity constant K were on the whole substantially independent of whether the exposure to light was on one side or the other of the film, or whether it was

[12] Lüppo-Cramer, Phot. Rund., *61*, p. 199; 1924.

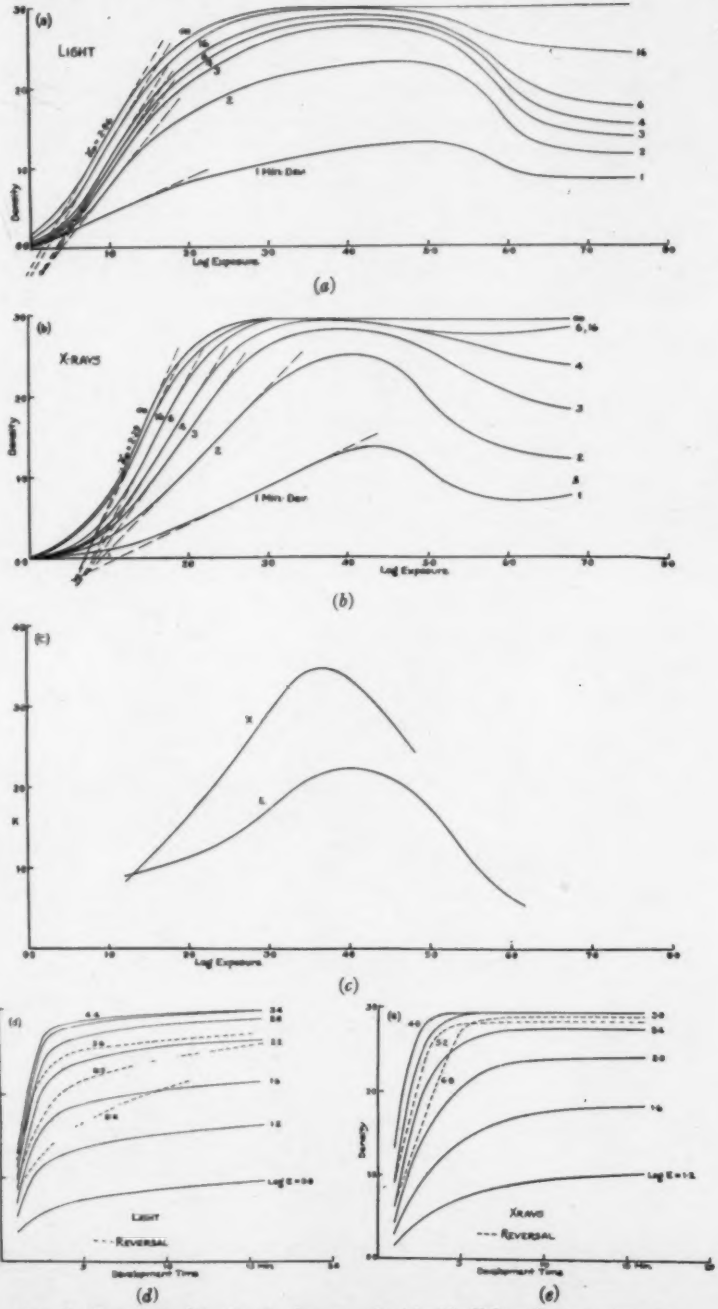


FIG. 9. *X-ray Film (No. 2); showing reversal with white light and x-ray exposures.*

equally divided between the two sides. Most of the differences observed were of the same order as experimental error.

These facts do not necessarily indicate that such phenomena as the production of reaction products of development, diffusion, and swelling of the gelatine are negligible in their effects upon development; the data merely show that whatever may have been the effects of these actions, the development as a whole was not much influenced by the variations occurring in the distribution of the affected silver in the emulsion layer. It is quite possible that the effect of distribution might be more apparent with exposures to the far ultraviolet, where the high absorption would tend to restrict the exposure to the surface layers.

The white light exposures on positive film (Figs. 1 and 2) were equally divided between front and back. This procedure should largely eliminate any effects due to differences in distribution of the x-ray and white light exposures in the emulsion layer.

It may be asked whether the differences in the penetration of light and x-rays in an individual silver halide grain are sufficient to cause appreciable differences in the actions of the two radiations; this seems rather unlikely, as it may be shown by the measurements of Slade and Toy[13] on the spectral absorption of silver bromide that ordinary light diminishes in intensity only a few per cent in passing through the average silver bromide grain.

It may be concluded that the differences in progress of development of x-ray and white light exposures were not due to differences in their penetration either through the emulsion layer or into the silver halide grain, but must have been due to some difference in the character of the latent images produced by the two types of radiation. It is quite possible that sensitivity to x-rays is constituted differently from sensitivity to light; it is well known that the two are not proportional to each other. If such is the case, it may be that the sensitivities to x-rays and to light are distributed differently within the grain, and that this produces a difference in the manner and rate at which the developer reduces the grain.

The tendency of the straight line portions of the characteristic curves for various development times to meet in a point is shown by the figures. In curves of observed data, this tendency is interfered with by the greater fog over the lower image densities, especially for the longer development times. The method of fog correction used removes this

[13] R. E. Slade and F. C. Toy, Proc. Roy. Soc., *97*, p. 181; 1920

interference, and brings more of the straight portions of the curves in line with a common point; the data on x-ray films of Fig. 3 shows all the straight line portions passing through or very near a common point;

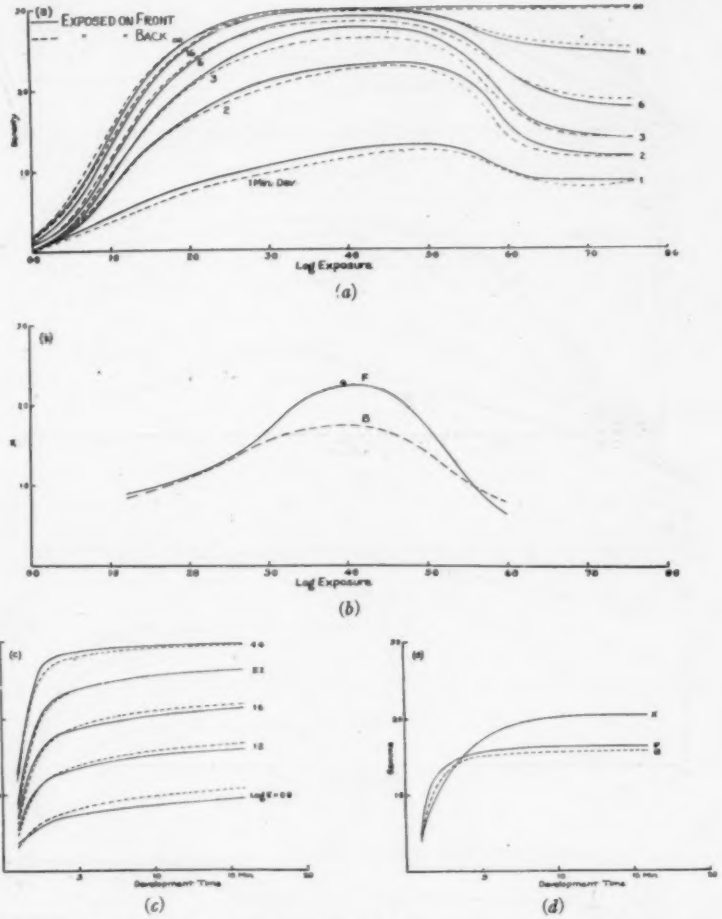


FIG. 10. *X-ray film (No. 2); exposures to white light showing reversal, comparing exposures on the front of the film with exposures on the back.*

positive film (Fig. 2) shows a common intersection point for most of the times of development; the curves for the longer development times show a shift toward shorter exposures which prevents their straight

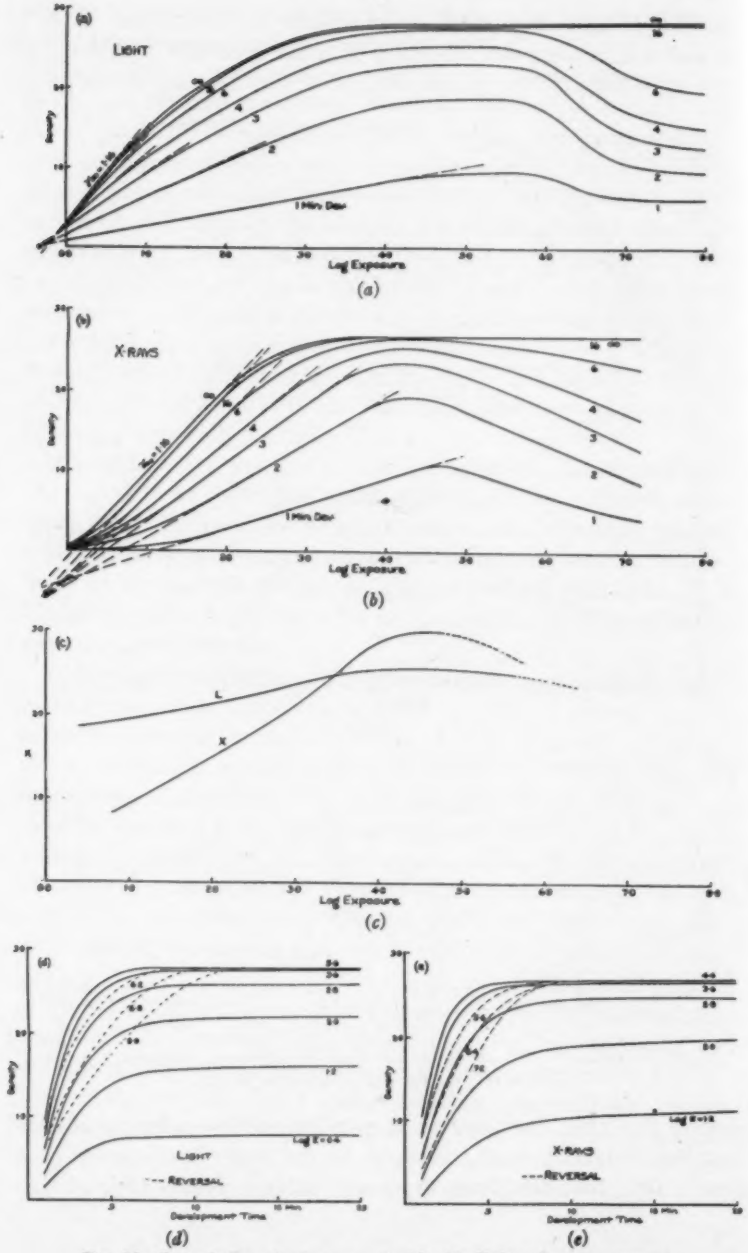


FIG. 11. *Portrait film, showing reversal with white light and x-ray exposures.*

line portions from passing through a point with the others. In almost every case the intersection point for x-ray exposures was lower than that for white light exposures on the same material. Nietz showed that

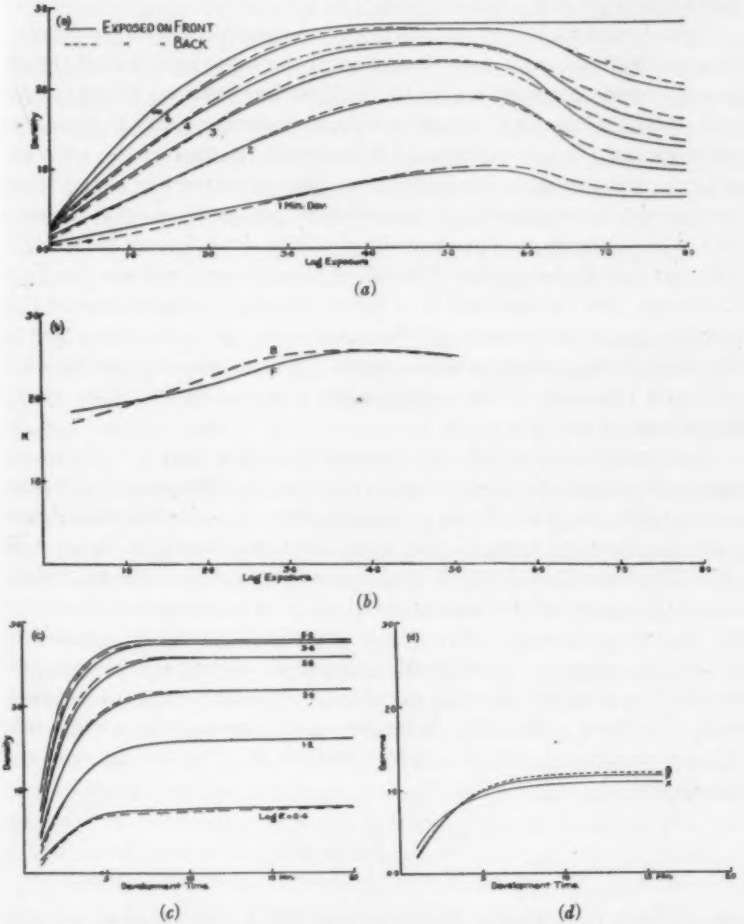


FIG. 12. *Portrait film; exposures to white light showing reversal, comparing exposures on the front of the film with exposures on the back.*

the common intersection point is lowered by the addition of bromide to the developer; it would doubtless be affected by the presence of soluble bromide in the emulsion and by the reaction products of development.

It must also be influenced greatly by the manner in which the various exposures develop; this factor appears to be chiefly responsible for the differences observed in the ordinates of the intersection points for x-ray and white light exposures.

If the straight line portions of the curves meet in a point, the density-time of development curves should be of the same form for all the exposures whose densities are on the straight line portions of the curves, and in such a case the velocity constant of development K should be the same for all such exposures. However in the case of the x-ray exposures, the straight line portion of the characteristic curve shifts toward shorter exposures as development proceeds, so that there is only a short range of exposures all of whose densities are on straight line portions of the curves. This effect is much smaller for white light exposures, and in this case it is found that the velocity constant K changes but slowly throughout the range of exposures corresponding to the straight line portions of the curves. The increase in development rate with exposure is most rapid in the region of the shoulder of the characteristic curve.

Nietz reported that his development equation gave a satisfactory agreement with experimental data except at the beginning of development, where the densities as computed from the equation were lower than the observed values. The same effect was found in the present data. The x-ray data fitted the equation nearly as well as the white light data. The correction for fog improved the fit of the equation, especially for the lower exposures where fog is greater. It would be possible to fit the data more accurately with an equation having more constants; but for the purpose of showing the effect of exposure on rate of development, the Nietz equation is preferable, as it expresses the specific rate of development in terms of a single constant, K. The derivative of the equation is

$$\frac{dD}{dt} = D_\infty \frac{K}{t} e^{-K \log t/t_0},$$

which shows the velocity of development dD/dt can be analyzed into two factors, D_∞ representing the mass of silver available for the reaction, and another factor containing K which includes other than mass effects.

Plotting D_∞ against $\log E$ gives the characteristic curve corresponding to complete or infinite development. This is shown with each family of characteristic curves derived from the experimental data. The D_∞-$\log E$

curve is a measure of the mass of silver made developable at each exposure. The form of any characteristic curve for other than complete development depends not only on the mass of silver made developable at each exposure, but also on the manner in which each exposure develops. Any theory which attempts to account quantitatively for the form of the characteristic curve for other than complete development must express not only the relation between exposure and the mass of silver affected, but also the growth of density with development time for each exposure. It is obvious that the velocity of development dD/dt should increase with exposure owing to the increase in the mass of affected silver as represented by D_∞; the present data show also that the velocity of development was increased in another way by the exposure, as shown by the increase in K, an effect which continued after the mass effect had reached its limit.

The fact that development rate continued to increase with exposure after all the silver had been made developable shows that at least some of the grains developed in a shorter time due to the extra exposure. Studies of the mode of development of individual grains may throw some light on this effect. Svedberg[14] has shown that the number of development centers on the grains increases with exposure; presumably the development centers are the points where the exposure has affected the grain. A grain would be expected to develop faster if there were more centers from which development could proceed to reduce the grain. However the general impression seems to be that a grain develops very rapidly after the first visible reduction takes place and that the greater part of the time required to develop a grain consists of an induction period.[15] It is a question whether reduction of the grain is actually proceeding during the induction period without producing any effect visible under the microscope, or whether some other mechanism is responsible for the induction period. Much more investigation is required on the manner in which individual grains develop if the phenomena observed in the present study are to be better understood.

It now remains to be determined to what extent the differences in form and slope of the characteristic curves (D_∞-log E) for white light and x-rays were due to the differences in the penetration of the radiation into the emulsion layer. As shown in Fig. 13 *a* the x-ray characteristic curve (1) of x-ray film has a much higher slope than the white

[14] T. Svedberg, Phot. J., *62*, p. 310; 1922.
[15] L. F. Davidson, Phot. J., *65*, p. 19; 1925.

light curve (3) on the same material. By the following simple method, the white light characteristic curve (2) was derived which would be obtained if the exposing light were uniform in intensity throughout the thickness of the emulsion. The photographic density of the undeveloped x-ray film (emulsion layer) for the light used in the exposures was found to be 0.96. The film was imagined to consist of ten equal layers each of density of approximately 0.10. It was assumed that the exposing light diminished logarithmically in intensity in passing through the emulsion layer. It was also assumed that the developed density of a whole thickness of film was the sum of the developed densities of all the layers. By a cut and try method, the characteristic curve for a single layer was obtained, from which, by combining the effects of all layers, the white light characteristic curve (3) could be derived. The ordinates of this single layer curve were multiplied by 10 to obtain the characteristic curve (2) of the combined 10 layers for the case where each layer is considered to receive the same exposure. The white light curve (2) can now be compared with the x-ray curve (1) on the same basis, that of a uniform distribution of the intensity of the radiation throughout the thickness of the emulsion; curve (1) has a 50 per cent higher gamma than curve (2), and curve (2) only 8 per cent higher gamma than curve (3). It is apparent that only a small part of the difference between curves (1) and (3) is due to the difference in the distribution of the radiation in the emulsion thickness. While the assumptions used in deriving curve (2) from curve (3) are only approximate, the small effect produced by the procedure indicates that no serious errors are caused by the use of these approximations.

The white light exposures on positive film (Fig. 2) were equally divided on the two sides of the film, so that any effect due to the variation in light intensity through the emulsion thickness should be practically negligible, yet the γ_∞ for x-rays was 3.42 as compared to a γ_∞ of 2.95 for white light. The γ_∞ values on portrait film were about the same for x-ray and white light exposures.

Renwick[16] has pointed out that the derivative of the characteristic curve shows the relative masses of silver made developable at each exposure value; it is, in effect, a grain sensitivity-frequency curve, the number of grains of each sensitivity being represented by the density they contribute and sensitivities being expressed in terms of their reciprocals, the inertias. Aside from effects due to the variation of intensity

[16] F. F. Renwick, Phot. J., *61*, p. 10; 1921.

of the radiation in passing through the emulsion layer, the form of the derivative curve, and of its integral the characteristic curve, is determined by the distribution of sensitivities. Fig. 13b shows the derivatives of curves (1) and (2) of Fig. 13*a*, comparing the distribution of x-ray and white light sensitivities on the basis of equal distribution of intensity in the thickness of the emulsion. The x-ray derivative curve is higher and narrower than that for white light, showing that x-ray sensitivity is, in the main, confined within narrower limits than that for white light. At half maximum, the log E interval on the x-ray derivative curve is 0.91, corresponding to a variation of 1 to 8.1 in sensitivity, whereas for white light, the log *E* interval at half maximum is 1.51, or a

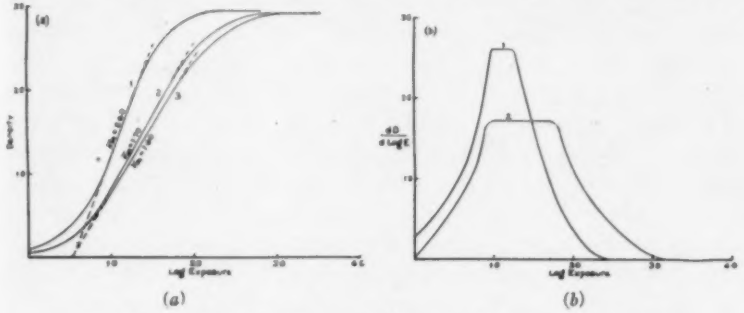


FIG. 13. *X-ray film (No. 1); characteristic curves (D_∞-log E) for complete development and their derivatives.*

Curve (1) for x-ray exposures, and curve (3) for white light, were derived from the experimental data; curve (2) was computed from curve (3) to obtain the white light characteristic curve for an assumed uniform distribution of intensity of the light in the thickness of the emulsion.

variation of 1 to 32.4 in sensitivity. It is apparent that the controlling factor in the difference in x-ray and white light characteristic curves is the difference in the distribution of x-ray and white light sensitivities. The characteristic curves (D_∞-log *E*) for x-ray and white light exposures on portrait film were of about the same form and slope, indicating that in this case the distribution of x-ray sensitivity is not much different from that of white light sensitivity.

The characteristic curves for partial development may have further differences due to differences in development rates for the two types of radiation. Thus the form of the characteristic curve for any time of development is largely governed by the properties of the latent image and its reaction with the developer; since the characteristics of the

latent image are so little understood, and may vary greatly from one emulsion to another, it is not possible to formulate any general rules governing the comparative photographic effects of x-rays and ordinary light. The varying results in x-ray sensitometry obtained by different observers must be attributed to the peculiarities of the emulsions used and can not be explained by any theory yet proposed.

One factor affecting the form of the characteristic curve is the variation of the photometric constant with density, and the difference in this variation for x-ray and white light exposures; the lack of sufficient data on this point prevents us from estimating its influence in the present experiments.

While in these experiments the penetration of the radiations into the emulsion layer had but little influence, Fabry and Buisson[17] have shown that the absorption of ultraviolet light by the emulsion is sufficient to affect considerably the slope of the characteristic curve, and may be high enough to determine gamma completely.

Higson and Toy[18] in their study of "The Factors which Determine Gamma Infinity" concluded that gamma infinity was substantially independent of the mass of silver halide per unit area, other factors remaining the same, and they reported an experiment in agreement with that view. This result would be expected if the absorption of the incident radiation by the emulsion is sufficiently high, but when it is low, as in the case of x-ray exposures, D_∞ at each exposure, and γ_∞, should be approximately proportional to the mass of silver halide per unit area.

TABLE 3

Experiment No.	Film	Gamma Infinity			
		Exposure to			
		X-rays	White Light Front	White Light Back	White Light Front and Back
1	Positive	3.42			2.95
2	X-ray No. 1	2.60	1.60		
3	X-ray No. 1		1.71		1.67
4	X-ray No. 1		1.90	1.95	
5	X-ray No. 2	2.29	1.86	1.91	
6	Portrait	1.16	1.16	1.21	

[17] C. Fabry and H. Buisson, J. Phys. et le Rad. *5*, p. 97; 1924.
[18] G. I. Higson and F. C. Toy, Phot. J., *63*, p. 68; 1923.

The gamma infinity values obtained with the different types of exposure are compared in Table 3. The films of each experiment were developed in the same batch of developer. The successive experiments on x-ray film No. 1 were made at intervals of about a month and show a progressive increase in γ_∞. Within experimental error, white light γ_∞ was the same whether the exposure was made on one side of the film or the other, or was equally divided between the two sides.

REVERSAL

The only reference we have been able to find on the subject of reversal due to heavy exposures with x-rays is that of Chanoz,[19] who obtained both reversal and re-reversal in radiographing a steel spring with long exposures. In the present study, it was found possible to obtain reversal on both x-ray film and portrait film with x-ray exposures which were experimentally feasible. The phenomena of reversal with x-ray and with white light exposures were compared on these two materials.

Mr. A. P. H. Trivelli of this laboratory informed us that his experiments (unpublished) with reversal had shown it to be a development phenomenon, occurring only with partial development and disappearing on complete development; the heavy exposures reduced the rate of development, but did not diminish the density to be obtained if development was sufficiently prolonged. A similar idea has been expressed by Krohn,[20] and Scheffers[21] also has maintained that ove-rexposure reversal is primarily a development phenomenon.

This was found to be the case in the present experiments. Sensitometric exposures were made to include the greater portion of the normal characteristic curve together with the first reversal. The sensitometric strips were developed for the usual range of development times. The data are shown in Figs. 9, 10, 11, and 12.

Reversal was found to consist of a decrease in the rate of development; throughout the reversal region the maximum density retained the same value it had reached in the heavier exposure portion of the normal characteristic curve; thus the reversal effect disappeared entirely when development was complete. The rate of development increased with a exposure in the region of the normal characteristic curve, reached a maximum, and then diminished in the reversal region.

[19] M. Chanoz, Comptes Rendus, *146*, p. 172; 1908.
[20] F. W. T. Krohn, Phot. J., *64*, p. 368; 1924.

In the case of x-ray film, reversal with white light exposures did not disappear completely at the longest development time used with the sensitometric exposures, 32 minutes; to test this point more thoroughly an experiment was performed using two exposures, one that giving the maximum rate of development, and the other a much heavier exposure giving reversal. Such exposures were developed for various times up to two hours. A similar experiment was carried out with x-rays. The resulting density-time of development curves are shown in Fig. 14. With the white light exposures, reversal did not totally disappear until 40 minutes' development; with x-rays, reversal disappeared at 7 minutes development. On portrait film, x-ray reversal had disappeared at 10 minutes development, and white light reversal at 12 minutes development.

As a rule, the Nietz development equation did not fit satisfactorily in the reversal region; the charts show how the density-time of development curve of the reversal region differs from that in the region of normal exposure. In using the velocity constant K to show the variation in development rate with exposure, the K-log E curve is drawn in solid line where the Nietz equation could be made to fit the data, and is extended in a broken line to indicate the probable course of an effective or average value of K in the region where the Nietz equation failed to apply.

Figs. 10 and 12 show comparisons of the reversal effects obtained with exposures on the front and exposures on the back of the film. The reversal phenomena appear to be substantially the same for exposures on either side of the film. In the case of white light exposures, the transition from the normal characteristic curve to the reversal effect occurs more gradually than in the case of x-ray exposures; the maxiam in the x-ray characteristic curves showing reversal are sharper than the maxima in the white light curves.

It is evident that investigations of over-exposure reversal should include a study of the associated development phenomena. It is probable that many of the conflicting results of experiments on reversal are due to differences in development conditions. Other photographic materials should be investigated to determine whether it is universally true that reversal consists of a decrease in rate of development, and disappears when development is complete.

[21] H. Scheffers, Z. Physik, *20*, p. 109; 1923.

[22] S. E. Sheppard, A. P. H. Trivelli and E. P. Wightman, Trans. Far. Soc. 19, p. 296; 1923.

It has been reported that the developed densities in the reversal region are finer grained than those in the region of normal exposure.[21] [22] It should be possible to determine by microscopic studies whether this is because the finer grains of the emulsion show a lesser reversal effect, and predominate in the developed density, or whether each grain is

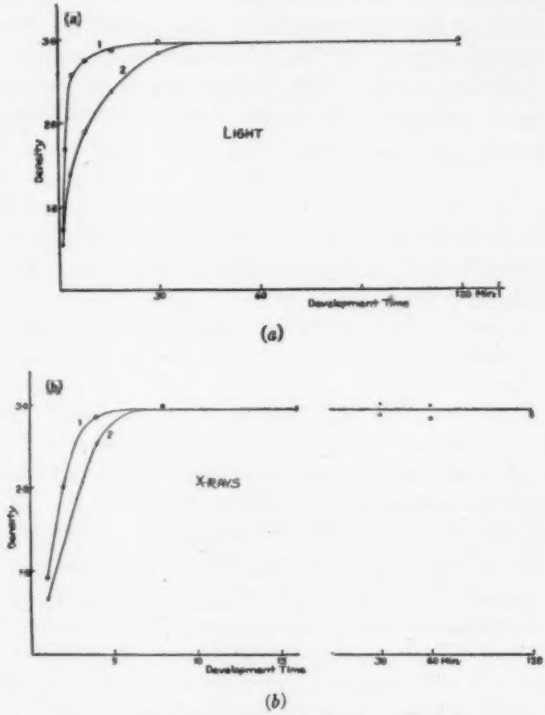


FIG. 14. *X-ray Film (No. 2); density-time of development curves.* Curve (1) is for exposure giving maximum development rate, and curve (2) is for heavier exposure giving reversal.

reduced gradually and is only partially developed when development is stopped. The latter possibility would explain Scheffer's[21] observation that reversal showed a decrease in the density and mass of silver developed, but no change in the number of grains of developed silver.

Svedberg, Schunk, and Andersson[23] have expressed the view that

[23] T. Svedberg, O. H. Schunk, and H. Andersson, Phot. J., *64*, p. 272; 1924.

reversal may be occurring to some extent in the region of normal exposure, and that its effect should be taken into account in studying the form of the characteristic curve and the relation between exposure and numbers of grains affected. In such investigations the silver halide is supposed to be completely developed; it would seem wise in each case to make a special test to determine whether reversal can be eliminated by sufficient development, and to make certain that development is carried to that degree. Microscopic studies of the mode of development of individual grains with reversal exposures may show how reversal can be distinguished in the development of ordinary exposures.

SUMMARY

A sensitometric study, comparing the effects of white light and x-ray exposures, was made on three photographic materials, a positive film, an x-ray film, and a fast portrait film.

The x-ray characteristic curve was found similar in form to that for exposures to light, showing a toe, straight line portion, shoulder, and maximum density.

The maximum density (D_m) that could be developed on each film was the same for either x-ray or white light exposures, and was found to correspond to the total silver available in the film, all of which had been affected by exposure and completely developed.

Each film showed a variation of development rate with exposure. That the observed increase of development rate was due to exposure is shown by the fact that after sufficient exposure was given to make all the silver developable additional exposure caused the same quantity of silver to develop more rapidly. With all three films, the variation of development rate with exposure was greater for x-rays than for white light, and the maximum development rate reached with x-rays was greater than that obtainable with exposures to light; these effects were the most pronounced in positive film, and showed the least in portrait film.

The form of the characteristic curve, for complete development, was found to be governed largely by the distribution of sensitivities; this distribution may be quite similar for x-rays and white light, as in the case of portrait film, or it may be quite different for the two radiations, as was found with x-ray film (No. 1). The properties of the latent image were also responsible for the differences in the mode of develop-

ment of x-ray and white light exposures. The distribution of the exposure in the thickness of the emulsions had but slight influence on the form of the characteristic curve or the progress of development.

Reversal due to over exposure was produced on x-ray and portrait films, with both x-rays and white light. Reversal was found to consist of a progressive decrease in rate of development, but not a decrease in the mass of silver developable. Complete development with all the reversal exposures gave the same maximum density as was obtained in the region of normal exposure, and which had been found to be that due to the reduction of all the silver in the film. Thus the reversal effect was observed only with partial development, and disappeared entirely on complete development.

The phenomena observed in these experiments were due largely to the characteristics of the latent image, and may therefore vary considerably from one emulsion to another for reasons not now understood.

We wish to express our thanks to Mr. Francis N. Gunderson for his able assistance in the experimental work.

EASTMAN KODAK CO.,
ROCHESTER, N. Y.,
OCTOBER, 1925.

Determination of the charge-mass Ratio for Protons.—Stetter used the principle and many details of Aston's mass-spectrograph to determine the e/m ratio for the particles driven out of paraffin (which for the present purpose is equivalent to very condensed hydrogen) by alpha particles. Owing to the high speed of these particles a very high electric field strength was requisite, demanding an available voltage of 15,000, a high vacuum to prevent sparking and a multitude of precautions; the magnetic field amounted to some 20,000 gauss. Other necessary modifications were a system of long parallel channels for the slit, and a setting of the ZnS screen normal to the beam. The apparatus and measurements are described in a long but unusually interesting narrative. Test experiments on α-particles gave the expected result (not so stated as to give the mean value nor probable error of the observed e/m, however); and then measurements on the particles coming from a cylinder of paraffin enclosing some radon were made, showing a group having the right e/m for protons within a few per cent. (This, however, was the best of a number of trials). This appears to be the best evidence thus far offered for the nature of the particles.—[G. Stetter, Radium Inst., Vienna; ZS. f. Phys., *34*, pp. 158–77; 1925.]

KARL K. DARROW

Stationary States of the Nitrogen Molecule.—Birge has deduced from the band spectrum of nitrogen four electron configurations *A B C D*, the energy values of which referred to that of *B* as zero, are respectively -1.4, 0, $+2.1$ and $+3.7$ equivalent volts. These values are deduced from the "zero bands" which correspond to transitions between states in which the atoms in the molecule are not vibrating. The first group of positive bands involves the transition *BA*, the second the transition *CB* and the third the transition *BD*. Bombarding N_2 molecules with electrons in the conventional way as developed by Hertz and using a photographic method to determine when the zero band of the second group first appears, Sponer locates its threshold potential at 13.0 ± 0.3 equivalent volts; this accordingly is taken as the energy-value of configuration *B* reckoned from the normal state. Extrapolation by a Ritz formula from the terms *A*, *C* and *D* to a convergence-limit indicates 16.3 for this, a value taken to be near the ionizing-potential of N_2. The negative group of bands has a threshold-potential determined as 19.6 and corresponds to a transition involving an energy-change of 3.1; not a bad agreement with the supposition that these are emitted when an *ionized* N_2 molecule returns from an excited state into its normal state. Sponer revives the theory that activated nitrogen consists of N atoms, with interesting though not clinching arguments.—H. Sponer, Gottingen; ZS. f. Phys., *34*, pp. 622-633; 1925.]

KARL K. DARROW

Rotation-spectrum of HCl vapor.—Exploring the absorption spectrum of HCl vapor in the region from 40 to 100μ, by Rubens' method with some refinements (the source of light being a Welsbach mantle, the dispersing apparatus a wire grating of spacing 0.4 or 0.8 mm, the short-wave light being filtered out by a lampblack screen and the whole light path but for 5 cm being in dry air or dry HCl) Czerny found a sequence of absorption peaks spaced almost uniformly in frequency which he attributes to transitions of the HCl molecule between consecutive permitted rates of rotation, no other change occurring (i.e. neither electron transition nor change in the amplitudes of vibration of the atoms). The frequencies stand approximately in the ratios 9:11:13:15:17:19:21, which is taken as evidence that the permitted rates of rotation are governed by half-quantum numbers (i.e. that the permitted values of angular momentum are all odd-integer multiples of a common unit). The energy values for these various permitted rates of rotation agree well though not perfectly with those deduced from bands in the higher-frequency regions of the spectrum, due to changes in the rate of rotation combined with other changes.—[M. Czerny, Berlin; ZS. f. Phys., *34*, pp. 227–44; 1925.]

KARL K. DARROW

A DEVICE FOR DETECTING SMALL CHANGES IN AN ELECTRIC CURRENT

By R. T. Cox and C. J. Pietenpol

It is sometimes desired to detect changes in an electric current much smaller than can be indicated by an ammeter inserted directly in the line. A simple and highly sensitive device for this purpose is the bridge the use of which in optical pyrometry has been described by Schofield and Gall.[1] It is essentially nothing more than a Wheatstone bridge of which one arm is a hot filament in vacuo. The bridge is inserted directly in the line. A very minute change in the line current will then change the temperature and hence the resistance of the filament enough to throw the bridge appreciably out of balance.

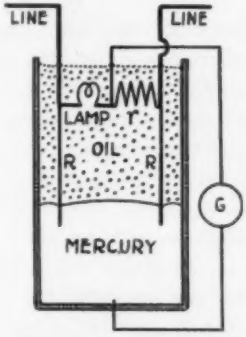


Fig. 1. *Diagram of Bridge.*

The arrangement shown in the figure was found convenient. The containing vessel is a glass tube 35 cms in height and 3 cms in diameter. It is filled partly with mercury, used in varying the resistances, and the rest of the way with oil, as a shield against transient external thermal conditions. The filament is a miniature lamp of the kind used in flashlights. The rate at which its resistance changes as the current passing through it is varied reaches its maximum value (about 100 ohms per ampere) when the current is 0.14 ampere. The resistance is then 3 ohms. The resistance r is a fixed resistance, also of 3 ohms. The two other resistances R, R of the bridge are furnished by two similar straight

[1] Jour. Sci. Inst., 7, p. 193; 1924. See also Bash, U. S. Pat. 1 376 666; 1921.

wires. The ends of these wires dip in mercury, and the wires can be raised and lowered together by a screw, so that their resistances can be varied but remain always equal. To balance the bridge it is then necessary so to adjust these wires, that the current through the lamp is exactly such as to make the resistance of the lamp equal to the resistance r.

The sensitivity of the bridge is found as follows. Let J be the current in the line, and suppose that the bridge is balanced. Now suppose this current changes by a small amount ΔJ. If the very small current passing through the galvanometer be neglected in comparison with the currents in the other parts of the bridge, the application of the familiar equations for a network gives us (to the first order of small quantities) the equation:

$$\Delta J = \frac{2rJ + ai(J-i)}{i^2 ra} \Delta V$$

where i is the current through the lamp when the bridge is balanced, a is the rate of change of the resistance of the lamp with the current flowing through it, ΔV is the potential difference across the galvanometer, and the other symbols have the meanings already assigned to them. With the values already given for the constants of the bridge, and for a line current of 1.5 ampere, this expression becomes approximately $\Delta J = 5\Delta V$.

On the galvanometer used, a deflection of 1 millimeter corresponds to a potential difference across the galvanometer terminals of 2.5×10^{-6} volts. From this and from the equation just given, it follows that the change in the line current corresponding to a deflection of 1 mm is 13×10^{-6} ampere or about a thousandth of one per cent.

NEW YORK UNIVERSITY,
NEW YORK, N. Y.,
DECEMBER 14, 1925.

TURNING ON AND OFF LIGHTS WITH THE PHOTOELECTRIC CELL*

By J. Kunz and V. E. Shelford

It appears that solar radiation may have important effects upon the rate of multiplication and vigor of various plants and animals. One source of difficulty in carrying on experiments where sunlight is used arises in connection with the supplying of artificial light to take the place of the sun when it is obscured.

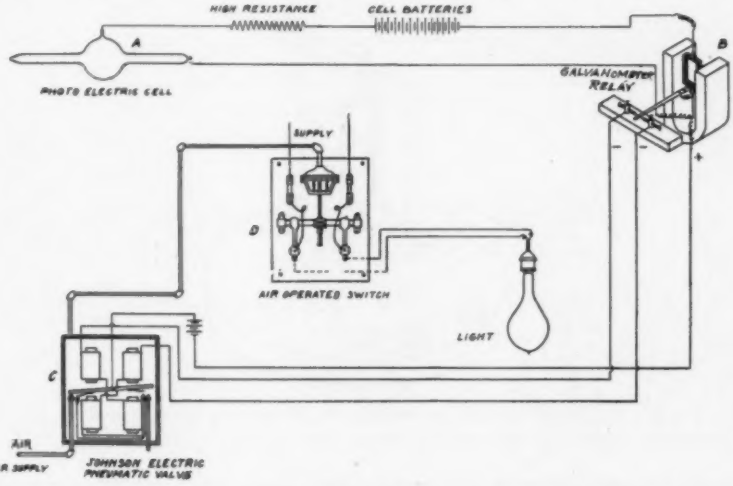


Fig. 1. Diagram of equipment for turning on and off lights. A, photoelectric cell; B, galvanometer relay made from a Leeds and Northrup recorder galvanometer; C, Johnson Service Company's pneumatic valve (E. P. valve); D, Johnson Service Company pneumatic electric switch.

For this purpose the junior author combined (Fig. 1) the Kunz photoelectric cell *A* and a modified galvanometer *B* with two pieces of commercial equipment *C* and *D*, is frequently used in biological laboratories for turning on fans, closing the circuits to heat coils, etc. A galvanometer pointer was substituted for a two contact metallic thermostat tongue.

* Contribution from the Physical Laboratories. and the Zoological Laboratories (No. 273) of the University of Illinois.

The two contact thermostat consists of a bimetallic tongue with a contact point on each side, one to close and one to open some form of heating switch and is in general use in temperature control. The Electric Pneumatic Valve used by the Johnson Service Company of Milwaukee (Fig. 1, *C*) in regulating room temperatures has been employed. The valve rotates a lever through about 30 degrees by means of electromagnets in the bimetallic thermostat circuit, which opens and closes air ports. One contact turns on the heat, at the same time opening the circuit on that side and closing the connection with the warm contact. A Leeds and Northrup recorder galvanometer (Fig. 1, *B*) was first used by the junior author to move a hanging crotched wire (in place of the bimetallic sensitive tongue) against the side contacts. This, and

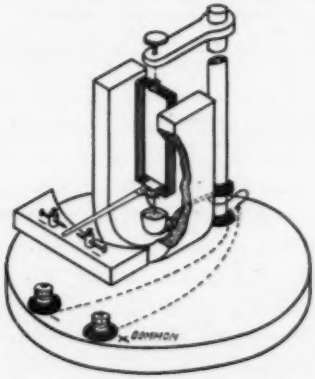


FIG. 2. *The essential parts of the mercury cup galvanometer. The galvanometer shield is omitted but supported the hard rubber pieces which hold the contact points and screws.*

a later modification of one of these galvanometers in which two small insulated wires passed downward in front of the upper suspension to a long pointer, operated a Johnson Electric-Pneumatic valve (operated by batteries) in conjunction with a Johnson motor starting switch (Fig. 1, *D*) of large capacity, and turned on and off lights with large differences in light intensity on a photoelectric cell. The galvanometer proved too sluggish to move the accessories with certainty.

A small General Electric galvanometer relay designed by the senior author was also tried successfully, but only with large light differences.

The senior author developed a galvanometer relay with a mercury cup and dipping wire to take the place of the lower suspension (Fig. 2). The mercury cup carried a wire to a pointer with a contact on each

side, as well as to the galvanometer coil. This operated the relay and light switches with differences of less than 100 foot candles on a photoelectric cell. Much greater sensitivity is possible through increases in the voltage on the E. P. valve and in the sensitivity of the galvanometer. This makes practicable the operation of switches by small light differences.

The Leeds and Northrup recorder galvanometer was then modified by connecting the upper end of the lower suspension directly to the pointer. (Fig. 1, *B*) The E. P. valve usually operates with three dry cells but its action is quickened by the addition of more up to six or eight. This galvanometer suspension will heat with more than three cells.

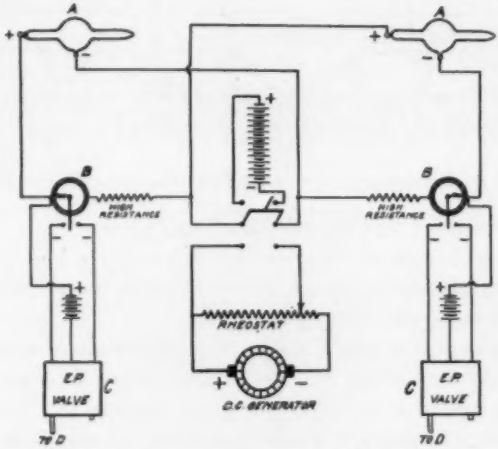


FIG. 3. *Diagram of the wiring used in connection with the two complete outfits used in the summer of 1925. The generator and emergency batteries are shown. Other wirings gave trouble which was possibly due to imperfect insulation but this particular arrangement works perfectly even when one cell and one galvanometer operates both E. P. valves and accordingly both lights.*

During the summer of 1925 two photoelectric cells of the ordinary physical laboratory type operated lights for four and one-half months with 100 volts taken from a 110 volt D. C. generator, and with one megohm Divan resistance unit in series (Fig. 3). The cells were located in a glass roofed house where the temperature reached a maximum of 120°F and remained near 100°F during much of the day. They were exposed to sunlight after passing through double strength window glass and the voltage remained on them at all times. Both of the gal-

vanometers were used, adjusted so that whenever the sun outside the glass roofed room gave only a dull shadow, the lights went on, and when the shadow became distinct, they went off. There was no evidence of deterioration of the cells sufficient to interfere with their operation. The cells were mounted in wire baskets (Fig. 4) and fastened to a clamp and ring stand so they could be turned to face the sun. The mechanic in charge turned the cells to face slightly toward the sun, two or three times per day, otherwise they operated without adjustment for the entire summer period turning on lights adjacent to chinch bug cages whenever a cloud passed or the sun was dulled.

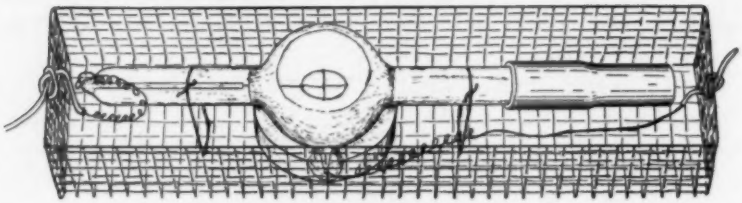


FIG. 4. *A physical laboratory type of photoelectric cell mounted for use in turning on lights.*

The two essential features of the apparatus are:

1. The breaking off of the circuit when a contact is made by the pointer. This eliminates the backward swing of the galvanometer due to spark and make and break phenomena.

2. The mercury cup which makes possible the use of a sensitive galvanometer and the passing of considerable current through the pointer to render the action of the relay sharp and positive.

The equipment renders it possible to automatically turn on interior factory lights, searchlights or street lamps with small differences in light. The difficulty relative to the cell having to face the source of light would not be serious in the case of interior lighting. A cell equally sensitive from all sides has been developed, but due to glass blowing difficulties only two have been produced and now the difficulties are being overcome.

The writers are indebted to Dean A. H. Daniels for Graduate School Funds, Professor A. P. Carman and Professor H. B. Ward for their support of the project.

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AN OXYGEN-GAS GLASS BLOWING LAMP

By Howard M. Elsey

It is difficult to design a satisfactory single tip blast lamp for use with air and natural gas. On account of the slow propagation of a flame through such a mixture, any attempt to get a "hard" flame causes the flame to blow out. For this reason, it is often desirable to use an oxygen-natural gas flame in the natural gas regions, particularly as the higher temperature obtained with such a flame is necessary in work with resistant glasses such as pyrex and silica.

As oxygen is usually purchased in cylinders under high pressure, a reducing valve of some kind is necessary to lower the pressure before introducing the oxygen into the blast lamp. However, the ordinary diaphragm pressure reducing valve is not satisfactory for intermittent use in unskilled hands.

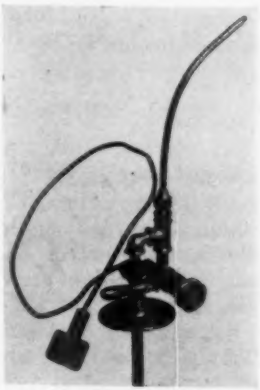

Fig. 1. *An oxygen-gas blowing lamp.*

For some time, a special form of lamp has been used in this laboratory which has proved quite useful even in student hands. The lamp is illustrated in Fig. 1. The oxygen is brought, at high pressure, from the cylinder in an ordinary 3/16″ gauge seamless copper tubing such as is used in gasoline lines. This tubing is fastened by a Lunkenheimer type

compression coupling to a brass needle valve. This needle valve has a long jet which extends up into the brass tee and the oxygen, when introduced through this nozzle, helps draw the gas in from the side as through an injector. The needle is made of monel which is not corroded so rapidly by the high oxygen pressure as is iron and which forces a new seat in the brass when necessary. A less expensive needle and one fully as good could be made by tipping a brass needle with monel.

The nozzle is of 1/4″ seamless copper tubing which is threaded inside at the upper end to take different sized tips. At the bottom, the nozzle is fitted to the lamp with a Lunkenheimer compression coupling which allows the flame to be readily pointed in different directions. The remainder of the lamp may be readily assembled from ordinary pipe fittings.

This type of lamp will give a very hot, beautifully pointed flame which is satisfactory for most laboratory glass blowing especially when used in conjunction with a Meker burner for preheating. Its chief fault is in not giving a large flame which is necessary in such operations as blowing bulbs. This fault may be overcome by mounting the upper part of an ordinary Meker burner in place of the usual stem and tip.

This second type of lamp gives a much broader flame which is useful in many operations though still too hot for best results in glass working.

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Normal cathode Fall and correlated Features of the Noble Gases.—New measurements of the normal cathode-fall V_n (defined as the minimum P. D. obtained between parallel broad flat electrodes when these are gradually moved towards one another during the continuance of the discharge), the width of the Crookes dark spaced d_n and the current-density i_n, are quoted for Kr and Xe. The cathode material was iron (with Kr, cathodes of Al and Pt also were used). The quantities i_n and d_n vary as p^{+2} and p^{-1} respectively. A tabulation of these quantities for all the noble gases discloses some interesting relations: V_n is close to 160 volts for the first three, rises sharply to 215 for Kr and 306 for A; d_n falls steadily from 1.9 cm for He to 0.23 for Xe (at 1 mm pressure); i_n has a high sharp maximum at Ar; the voltage drop per mean free path in the gas filling the Crookes dark space rises steadily from He to Xe, which suggests that the ability of an ion of a noble gas to drive an electron out of the cathode by striking it diminishes rapidly with increasing mass.—[A. Guntherschulze, Reichsanstalt; ZS. f. Phys., *34*, pp. 549–552; 1925.]

KARL K. DARROW

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